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2572

気象庁 英文 海洋 報告

第 25 卷 第 2 号

THE OCEANOGRAPHICAL MAGAZINE

Vol. 25 No. 2

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DEC 2 1974

FISH & WILDLIFE SERVICE

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Published by the Japan Meteorological Agency

March, 1974

Marine meteorological buoy of the Japan Meteorological Agency

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(Received on December 20, 1973)

Abstract: The construction and deployment of the first operational buoy are reported. A disc buoy with diameter of 10 meters and weight of 43 tons is designed to withstand 60 m/sec winds and 15 meter waves. The platform is capable of operating unattended for 14 months in operational program. Sixteen parameters are measured at the station and are reported automatically every three hours on 8 and 12 MHz HF bands.

The buoy is anchored with plastic ropes. The data are received at the Weather Communication Station of JMA and computer processed to enter the Global Telecommunication System in the WMO Code Form FM. 24E—Ship.

1. Preface

The first of the series of operational buoys for automatically gathering oceanographic and meteorological data from the marine environment was stationed on 6 August 1973. The 43-ton buoy was anchored in the Pacific Ocean in 4,200 meters of water about 350 nautical miles southwest of Tokyo. It is scheduled to remain on site until next April, transmitting environmental data (Fig. 1 and Photo).

The program to develop a national system of environmental data reporting buoy is conducted by the Ocean Buoy Committee of the Japan Meteorological Agency (JMA). The program consists of three phases in succession, for the development and operation of buoy systems, pilot buoy systems, operational buoy systems and satellite-linked buoy systems.

The first buoy of the series of pilot buoys was fabricated in 1968 (fiscal year) and second one in 1970 (ditto). Test deployment and operation of the buoys have been carried out in the Japan Sea ever since (Akamatsu, 1970).

Experience gained by deployment and operation of the buoys, together with important engineering and environmental data obtained, provided great impetus to the development of the operational buoy, construction and deployment of which will be described here.

Four operational buoys are scheduled to be stationed in the oceans around Japan. They are designed to withstand 60-m/sec winds and 15-meter waves. Each platform is capable of operating unattended for 14 months in operational programs.

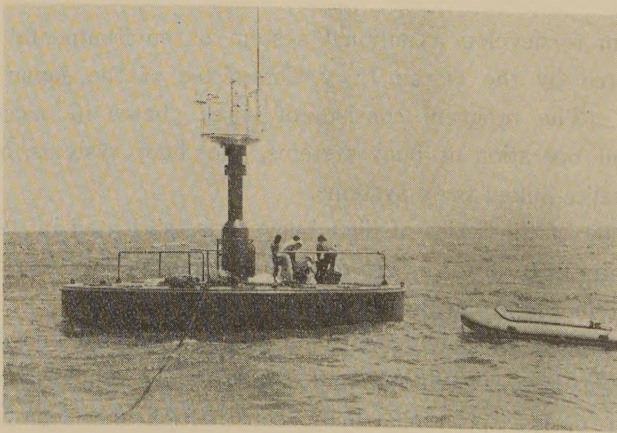
Sixteen parameters are measured at the buoy station; they are, wind direction and speed, air temperature and dew point, air pressure, water temperature at the depths of 3, 20 and 50 meters, wave height and frequency, global radiation, orientation of the buoy, current speed and direction, salinity and inclination of the buoy.

Measured data are reported automatically every three hours on two preset frequencies, 8 and 12 MHz bands, initiated by a crystal clock in the buoy. Each transmission is sent 4 times in sequence, two times on 8 MHz and another two on 12 MHz.

All electronic devices used in the buoy are of solid state and housed in steel cabinets filled with dried nitrogen gas, and completely sealed against marine environment.

The design philosophy with regard to buoy maintenance is based on maximum reliability and minimum on station servicing.

The receiving station is installed at the Weather Communication Station of JMA, where data are processed via electronic computer and disseminated to users by the Automatic Data Editing and Switching System (ADESS) of JMA.



Installation of current meter at the deployment station

2. Buoy

Fig. 1 shows the construction and inside layout of the buoy. The disc shape negates the need for considering, as separate entities, the directional forces exerted on the buoy in the form of wind, wave and current. Because these forces are often simultaneous and are operating from different directions, yawing, rolling and the resultant increase tension on the mooring line. A 30° sloping face is selected

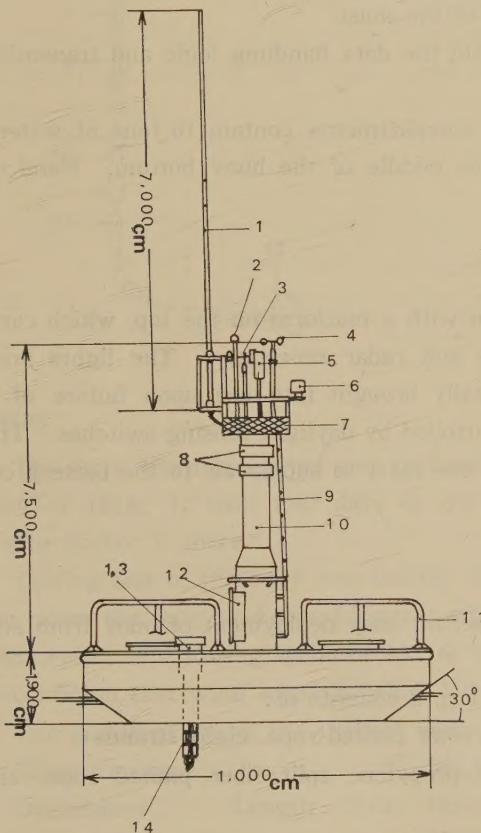
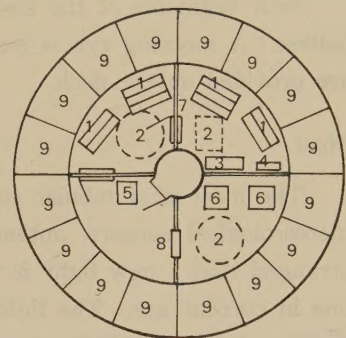


Fig. 1-1. Outside view of the buoy

- 1 Antenna 2 Radiation sensor 3 Wind vane
- 4 Anemometer 5 Psychrometer 6 Compass
- 7 Platform 8 Air intakes 9 Ladder 10 Mast
- 11 Hand rail 12 Hatch 13 Sensor well
- 14 Current meter



- 1 Primary batteries
- 2 Hatches
- 3 Extra batteries
- 4 Secondary batteries
- 5 Data handling logic
- 6 Transmitters
- 7 Battery compartments
- 8 Instrument compartments
- 9 Ballast segments

Fig. 1-2. Layout of the inside.

as compatible with wave slopes, permitting the buoy to ride up and down the waves with reduction in drag and tendency to capsize.

Buoy structure is divided into two parts, the discus hull and the mast. The structure is made almost entirely of shot-blasted mild steel.

Discus hull

The discus hull has a 10-meter diameter and 1.9-meter depth. It contains most of the systems and services for the buoy. It is divided into four center-core compartments surrounded by a further 16 segmental compartment. Access to the centre compartments is from the base of the mast.

Two of the core compartments hold the data handling logic and transmitters and another two hold batteries.

Four segments of the surrounding compartments contain 10 tons of water as ballast. A mooring eye is located in the middle of the buoy bottom. Hand rails are provided on the deck.

Mast

The mast is of tubular construction with a platform on the top, which carries meteorological sensors, antenna, lights and radar reflector. The lights are so arranged that a new light is automatically brought into use upon failure of the one in current use. The lights are controlled by daylight sensing switches. There are two air intakes close to the top of the mast to supply air to the battery compartments.

Mooring

Mooring system was designed to permit easy deployment of buoy from small ocean vessels by unskilled personnel.

The mooring system illustrated in Fig. 2 consists of:

3,800 meters (7.6 tons) 49 mm ϕ Polyester plaited rope, eight strands

1,000 meters (2 tons) 60 mm ϕ Polypropylene split fiber plaited rope, eight strands

125 meters (2.5 tons) 30 mm galvanized chain

1 piece (500 kg) mushroom anchor

An outboard depth recorder is used to sound the depth of the station. The scope (ratio of mooring rope length to depth) is selected as 1.1, giving excursion radius of 2 km,

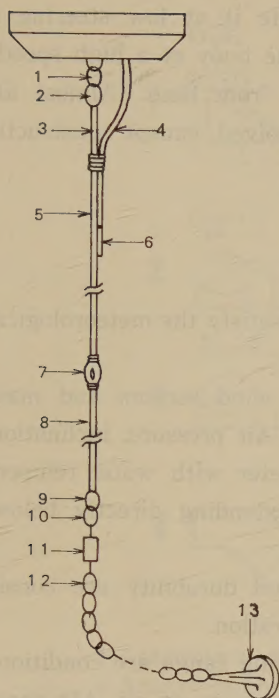


Fig. 2. Mooring system

- 1, 10, 12 Shackle
- 2, 9 Thimble
- 3, 5 49 mm ϕ Polyester plaited rope, eight strands
- 4 Thermometer cord
- 6 Thermometer probe
- 7 Splice
- 8 60 mm ϕ Polypropylene split fiber plaited rope, eight strands
- 11 Swivel
- 12 30 mm ϕ chain
- 13 500 kg mushroom anchor

Towing

The buoy was transported and anchored by a chartered ship under the supervision of JMA. It took four days to tow the buoy to its site and another seven days to anchor it there.

Towing test of the buoy was carried out before its departure. It proved that even when the buoy was towed against wind, it plowed the waves without getting under water, at a towing speed of 6 kt or more with trimming angle of 5°, under the condition that wind speed is below 15 kt and waveheight is less than 5 meters.

The specifications of the tugboat used were as follows.

Gross tonnage	245 tons
Dimensions	Length 33 m, Breadth 9 m, Depth 4 m
Main engine	1,300 I.H.P.
Cruising speed	full ahead 12 kt, half ahead 8 kt, slow ahead 6 kt
Cruising range	7,500 miles
Derrick	5 tons

In general, it is harmful for ship engine to operate it at low steering speed for a long time, it is, therefore, preferable to tow the buoy at a high speed, say 10 kt or more, especially when it is to be used far from base. Almost all the factors determining the towing speed of buoy are solved, except construction of sensors that are endurable to high towing speed.

3. Sensor

The measurement list of the buoy is compiled to satisfy the meteorological and oceanographical real time data requirement.

Air temperature, dew point, global radiation and wind sensors and magnetic compass are located on the platform of the mast. Air pressure, inclination and wave sensors are located in the hull. The current meter with water temperature and electric conductivity sensors is hull mounted, extending directly below the buoy.

Improvements in sensor design, reduced weight and durability are considered a prime factor for achieving extended unattended operation.

All sensor signals corresponding to each measuring range are conditioned so as to output DC 0–1 volt to an analog-multiplexer in front of an AD converter (Fig. 4).

Wind sensor (Fig. 3-1 and 2)

Three cup anemometer and wind vane are used to provide wind speed and direction respectively. Output of a dynamo that is coupled to the cup axis is fed to condensor-resistance filter network so as to eliminate short-time fluctuations in wind speed.

Wind vane drives a 2,000-ohm variable potentiometer through gears with a ratio of 2:1, resulting two revolutions (angle of 720°) of vane to give one revolution (360°) of potentiometer. To avoid uncertainty at 0° (or 360°) of vane angle, the potentiometer has two contacts at a distance of 180° . In conjunction with the output of the potentiometer, voltage comparators are used to sense that the output is within preset values, to cause the relay to change the another output. Outputs of wind vane potentiometer and compass make true wind direction.

Compass (Fig. 3-3)

The permanent magnet compass is mechanically coupled to a potentiometer

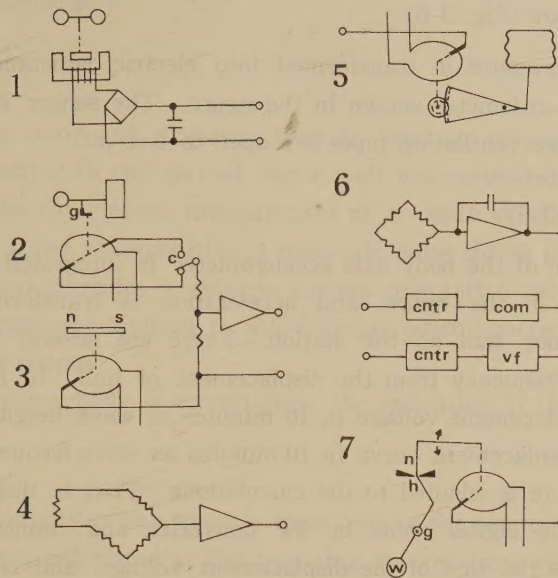


Fig. 3. Sensor system.

- 1 Anemometer 2 Wind vane, 3 Compass 4 Thermometer
5 Aneroid barometer 6 Wave sensor 7 Inclinerometer

position readout. It is hermetically sealed so that it can be immersed in water. The compass is mounted on the aluminum arm at the mast, thus removing it from the proximity of ferromagnetic materials which could influence its readings.

Air temperature and Dew point

A ventilated psychrometer with platinum thermometer probes are used for these measurements. Water drops are fed to the wet bulb at the beginning of each measurement, opening electric valve controlled by timing circuit. Water reservoir has a capacity of feeding water to the bulb for as long as 14 months. Ventilation fan is driven by brushless DC motor using Hall elements.

Temperature sensor's signal condition circuit is shown in Fig. 3-4. A standard bridge circuit output is fed to a chopper-stabilized operational amplifier to give 0–1 volt output corresponding to temperature of -10 to $+40$ °C respectively. DC–DC converter is used to supply power to the bridge so as to avoid mutual interferences between electric sources. Linearizing circuit is provided in the operational amplifier circuit to correct non-linearity errors of the bridge output.

Atmospheric pressure (Fig. 3-5)

Atmospheric pressure is transformed into electric resistance using aneroid-actuated micro-potentiometer shown in the figure. The sensor is installed in the battery room, where ventilation pipes are open to free air.

Wave sensor (Fig. 3-6)

Output voltage of the body axis accelerometer is integrated by a double integrator as shown in the figure, and acceleration is transformed into relative displacement of buoy hull on the station. There are several methods to draw wave height and frequency from the displacement of hull. In this case, we take an average of displacement voltage in 10 minutes as wave height, and number of zero-up-cross of displacement curve in 10 minutes as wave frequency. Digital data processing procedure is adapted to the calculations. That is, displacement voltage is transformed into digital value by VF converter and counted by a counter. Comparator checks the sign of the displacement voltage, and counts the number of sign changes from - to +.

Complementary MOS (C-MOS) are used in the circuit on account of low power dissipation.

Clinometer (Fig. 3-7)

Inclination of the buoy hull is a parameter of indicating sea state and weather condition at the station. A clinometer is installed in the hull, isolated from other sensors. Inclination of the weight held on gimbals pulls nylon string of an arm, mechanically coupled with a potentiometer, and inclination is transformed into electric voltage.

Global radiation

CdS (Cadmium Sulfide) is used as sensing element of global radiation, with electronic signal conditioning circuits.

Filters are attached in front of the element to standardize the output of the circuits. Contamination error of the protective glass is decreased with this filters also. Inclination error of the hull is not compensated due to its objective, that is, the global radiation is measured for monitoring weather condition that is useful for meteorological analysis.

Ruggedness and small size of the element make the installation and mainte-

nance of the sensor easier.

Current sensor

The Savonius rotor and direction vane is used to measure current vector. The sensor is mounted in the current meter well and extended below the bottom of the hull to make the current measurement at a depth of 2 meters. The rotor measures current speed, incorporating a magnetic pulse signal pick off. The direction vane employed provides a reliable current orientation relative to the sensor body. It is magnetically coupled to a low-torque potentiometer which provides a varying resistance output.

Direction of sensor body is corrected by the indication of the compass.

Salinity

Electric conductivity of sea water is measured by the electro-inductive coupling method. Salinity is calculated at the receiving station, from electric conductivity and water temperature.

Water temperature

The platinum thermomenter probes are installed at the depths of 3, 20 and 50 meters. A water temperature probe installed at the current meter, that projects below the buoy hull, makes the measurement at the depth of 3 meters. Other probes are attached to the mooring rope at the depths described. Temperature signal conditioning electronics are the same as that of air temperature shown in Fig. 3-4.

4. Transmitting system

Fig. 4 shows the outline of the measuring and transmitting system. Signals of each sensors are fed to terminals 1 to 16 of the analog-multiplexer composed of FETs (field effect transistor). When the FETs receive clock pulses, the analog signals are switched in numerical order to the AD converter, and are converted to BCD (binary coded decimal) values of three figures (=12 bits). The digitalized data are stored in the shift-register: SR sequentially.

In the sending mode, stored data in the SR actuate the gate circuit to pass $100\text{ KHz}+85\text{ Hz}$ or $100\text{ KHz}-85\text{ Hz}$ to the modulation circuit, in accordance with

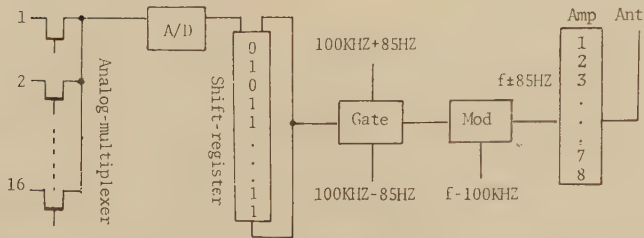


Fig. 4. Measuring and transmitting system.

data, whether they are 0 or 1. In the modulation circuit, incoming frequency from the gate circuit is mixed with frequency of $f\text{KHz} + 100\text{ KHz}$, giving $f\text{KHz} \pm 85\text{ Hz}$, where f is a carrier frequency.

Transmitter amplifiers are composed of eight parallel connections of high power transistor amplifiers and immersed in oil bath.

A stainless steel tube, 7-meter length and 50-mm diameter, is used as a common antenna for two bands, 8 and 12 MHz.

Overall specifications of transmitting system are as follows.

Carrier frequencies : 8,330.8 KHz
12,482.3 KHz

(assigned by the World Administrative Radio Conference)

Frequency stability : 3×10^{-7}

Band width : 300 Hz

Power of transmitters : 50 W

Modulation type : F1

PCM—FSK (pulse code modulation-frequency shift keyed)

Shift frequency : $\pm 85\text{ Hz}$

Signal form : NRZ (non-return to zero)

Signal speed : 75 bit/sec

The buoy is reporting automatically every three hours on 8 and 12 MHz bands in conformity with synoptic collection time.

Each transmission is sent four times in time sequence of 30 seconds, alternating on 8 and 12 MHz. It took 10 seconds for each transmission. Transmitting code has following format. (Fig. 5)

Y. KAWANO: Marine meteorological buoy

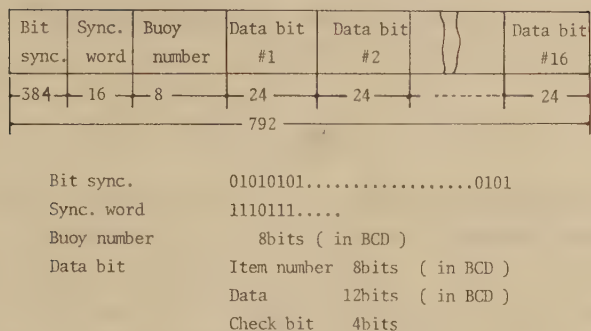


fig. 5. Code format.

Total bit : 792 bits

Bit sync. : 384 bits of alternating 1s and 0s

Synchronization word: 16 bits: 11101110010000

Buoy number : 8 bits (in BCD)

Data : 16 items × 24 bits

Item number : 8 bits (in BCD)

Data : 12 bits (in BCD)

Check bit : 4 bits.

5. Receiving station

The data from the buoy are received at the Weather Communication Station of JMA in the suburbs of Tokyo, and computer-processed to enter in the Global Telecommunication System in the WMO Code Form FM. 24E—Ship. Radio waves received at the station are amplified and demodulated, and they give pulse codes explained in Eig. 5. The pulse codes are fed to the digital printer to print out the data and are simultaneously entered into the computer, where following processes are carried out.

1. As same data are sent four times at each transmission, four data are checked and the reasonable one is picked out.
2. Data picked out are compared with previous data. When differences greater than the preset limits are found, the computer sends an alarm signal and print out the item concerned on I/O typewriter for the operator to check data manually.

3. Scale conversions, calculation of dew point and salinity, and code conversion for the WMO Code Form FM. 24E—Ship.

Conclusion

The buoy is operating satisfactory so far, despite some troubles occurred in towing and anchoring works.

Evaluation of the data is in progress according as increase of data available, and the data come up to the weather forecaster's expectations.

Major results of the program thus far increased confidence in deployment and measuring configuration.

The most important subject concerning buoy project hereafter seems to lower the operating cost and to improve the transmitting system.

The followings would be useful for the former item.

1. To extend on-site employment period.
2. To increase the ability of easy replacement of sensor, particularly under-water sensors, without having to disturb the mooring system.
3. To improve the mooring materials and emplacement techniques.

Though improvements of the signal format and the software of the computer at the receiving station will bring effective data transmission, the satellite will give a noticeable improvement for the system.

References

- AKAMATSU, H. (1970): The ocean data station buoys of the Japan Meteorological Agency. *Oceanogr. Mag.* 22, 25-94.

気象庁の海洋気象ブイロボットについて

河 野 幸 男

(気象庁・海洋気象部)

気象庁のブイロボット計画は、昭和 40 年度に 1 号機の製作を行って以来、2 号機の製作、1, 2 号機の運用、2 号機の改造などの段階を経て、昭和 48 年夏に実用機を四国南方 500 km の海域に定置するに至った。

本報告はこの実用機のシステムについて大要を述べている。

ブイは写真および Fig. 1 に示すような、直径 10 m の円板形のもので、バラストとして入れた約 10 トンの水を含めて、総重量は約 43 トンである。ブイは Fig. 2 のようにアンカーに係留されている。

ブイロボットの測定項目は、風向・風速・気温・露点・気圧・水温（3 層）・日射・流向・流速・方位・塩分量・傾斜である。測定は 00 Z から 3 時間ごとに、1 日 8 回行い、8 および 12 MHz の短波帯を使用して伝送している。

ブイロボットの電源は空気湿電池を使用していて、約 14 ヶ月間作動可能である。

ブイロボットのデーターは、気象通信所で受信され、ミニコンピュータ処理によって、点検・整理・演算後、国際通報型式 FM. 24E—ship によって ADESS に出力している。

ブイはタグボートで曳航して係留した。係留は、小さい船の不慣れな作業員でも実施できるように、取扱い容易なテトロンロープを主体とした簡単な構造とした。

On the changes of sea surface temperature in the western North Pacific Ocean

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and Etsuro KAMIHIRA

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(Received on Jan. 17, 1974)

Abstract: The sea surface temperature anomalies for every 5-degree squares in the western North Pacific Ocean are calculated for the data from 1956 to 1970.

The anomalies show a systematic pattern of change, that is, anomalies of the same sign continue for several years. The pattern of changes is nearly the same in each of the three regions, that is, the region south of the parallel 35°, the mixed one between the parallels 35° and 45°N and the Oyashio region north of 45° N, and shows significant phase lags among them. Spectral analysis of the data reveal also the peaks at 5- to 7.5-year period and other shorter ones which are found commonly in the western North Pacific Ocean.

1. Introduction

Statistical or empirical method of forecasting the sea conditions is now the only one, because numerical or dynamical method is just under developing. Statistical method is very useful now and even in future for predictions in the sea area except the western boundary region or predicting the average conditions over a rather wide sea area. In order to extrapolate the sea conditions statistically by using those of the past, long-term time series of parameters expressing sea conditions are necessary. It is also very important to grasp empirical law concerning the change of sea conditions or the interaction between the ocean and atmosphere by comparing the time series of parameters concerning sea conditions and atmospheric, geophysical and solar phenomena. For these purposes the sea surface temperature (SST) data are very useful.

In 1971, we started to calculate new monthly mean sea surface temperatures using data obtained during the period 1956-1970 and we planned to substitute these for the former one which covered the period from 1951-1960 which had a less homogeneous data coverage. we did not find any significant difference between them.

The new data were obtained from a series of ten-day SST charts by reading off the temperature at the center of each one-degree rectangle, and summing these ten-day values to obtain monthly value for that square. By using these data we examined the sea surface temperature deviations for a network of 5-degree squares in the area west of 180° and covering the latitudes 15°N to 50°N. The SST data in each 5-degree square are calculated by,

$$T_n = \frac{\sum_i \sum_j T_{ij} A_{ij}}{\sum_i \sum_j A_{ij}},$$

where T_n , T_{ij} and A_{ij} are the temperature at the 5-degree squares, the temperature at the 1-degree square and area factor, respectively.

Before presenting the analysis of the SST data, we will show some fundamental oceanic patterns which are characteristic of the sea-area around Japan. The south Equatorial Current flows westwards, shifts northwards and becomes narrower as it approaches the New Guinea coast. The Equatorial-Counter Current flow eastwards, and the north Equatorial Current flows from east to make up the bulk of the Kuroshio water. The Kuroshio flows along the coast of Japan and then turns to the east (the Kuroshio Extension). Here are shown some small scale but important pattern changes of the water masses—firstly the meanderings of the Kuroshio south of Japan and secondly the shearing of warm eddies from the Kuroshio Extension east of Japan. In this coastal area, temperature changes are mostly due to change in these patterns of flow. The Oyashio, although it is not so distinguished current as the Kuroshio, flows or situates south of the Kurile Islands, and extends south-westwards near the east coast of Japan. The Kuroshio Extension and the mixed waters between the Oyashio and the Kuroshio, flow further eastwards, which are called the west wind drift.

2. Analysis of the data

Seasonal changes of SST:

Figure 1 shows the seasonal change of the mean SST from 1956 to 70 in the blocks W_1 , W_2 , W_3 , W_5 and W_6 (shown in Fig. 7).

The maximum occurs in July in W_1 , between August and September in W_2 , and in August in the rest of the blocks, while the minimum in February in the southern blocks W_1 to W_3 and in March in the northern blocks W_5 and W_6 . The

difference of the maximum and minimum is about 5°C in W_1 , 6°C in W_2 , 9.5°C in W_3 , 11°C in W_5 and 8.5°C in W_6 .

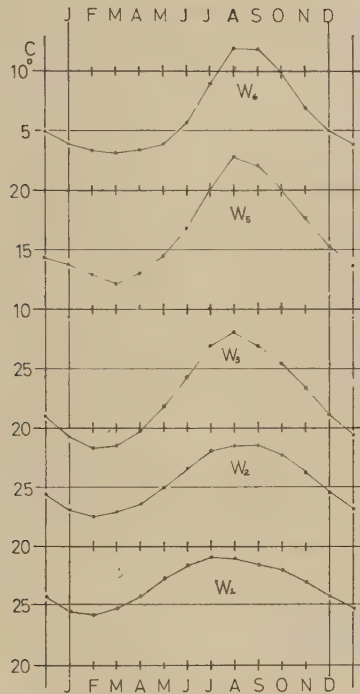


Fig. 1. Seasonal variations of mean sea surface temperature from 1956 to 1970 for the region W_1 , W_2 , W_3 , W_5 and W_6 (see fig. 7).

Time sequence of the data:

Figure 2 shows the time sequence of temperature deviation over the north Equatorial Current before it joins the Kuroshio. These figures show a systematic change warm periods in 1959/60, 1966/67 and 1969/70, and cold periods in 1956/57, 1962/63 and 1967/68. The amplitude of the changes is smaller than those found in the mixed zone and the Oyashio area. Figures 3 and 4 show the same things for the Kuroshio area zone from 25° to 35°N . The amplitudes of changes decrease eastwards and the durations of the same sign of deviation are shorter than in the other regions, especially short in the small sea areas, No. 27, 28, 29, 39, 41, 42 and 43. The periods are 2 to 3 years. When these short-period changes are summarized, we can

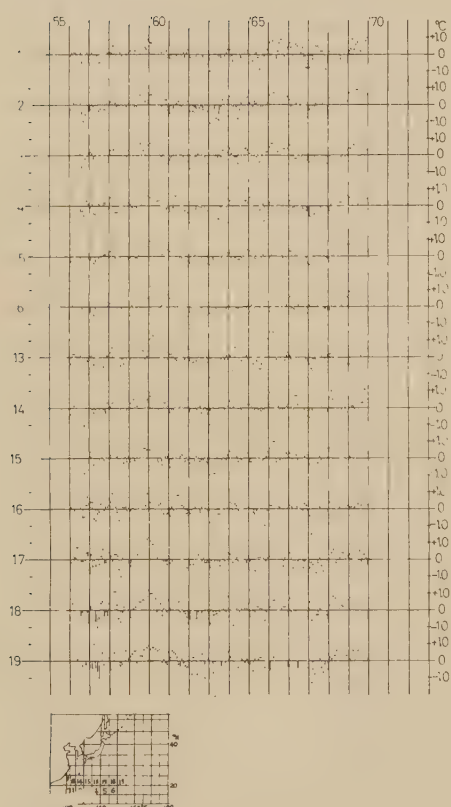


Fig. 2 SST anomalies in the 5 degree blocks, No. 1 to 6 and 13 to 19.

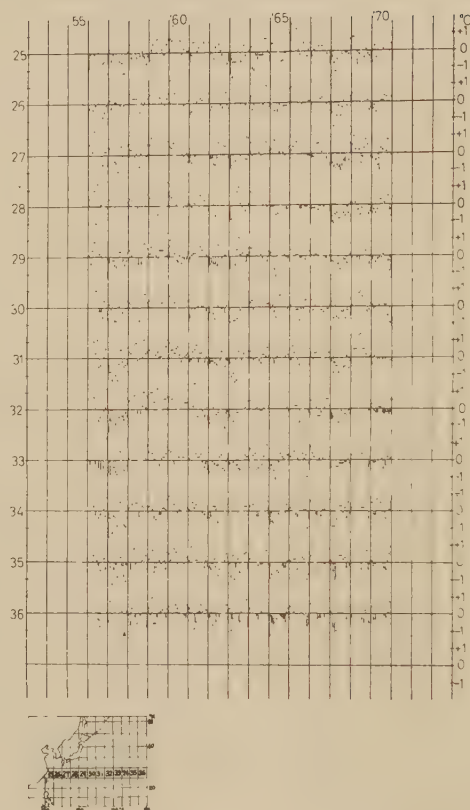


Fig. 3 SST anomalies in the 5 degree blocks, No. 25 to 36.

find warm periods in 1958 to 1961 (only in No. 37 to 45), 1966 to 1967 (not so significant) and 1969 (only in No. 45 to 47), and cold periods 1963 (winter), 1968 and 1970

Figures 5 and 6 are the same things in the mixed zone between the Kuroshio and the Oyashio. The amplitudes of changes are very large and the durations of the same sign are longer than in the sea region south of the parallel 35°N. In the southern part of the mixed zone, warm periods are found in 1955/56, 1960/61, 1966/67 and 1969, and cold periods in 1957/58 and 1965 (Figure 5). In the northern part of the zone, the warm periods are in 1955/56, 1961 to 1963 and 1967 to 1969, and cold periods in 1964/65 (Figure 6). The 5-degree squares labelled 69 to

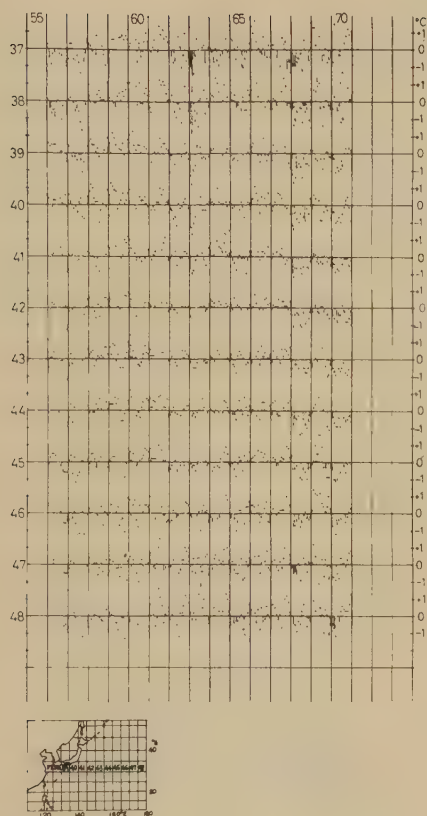


Fig. 4. SST anomalies in the 5 degree blocks, No. 37 to 48.

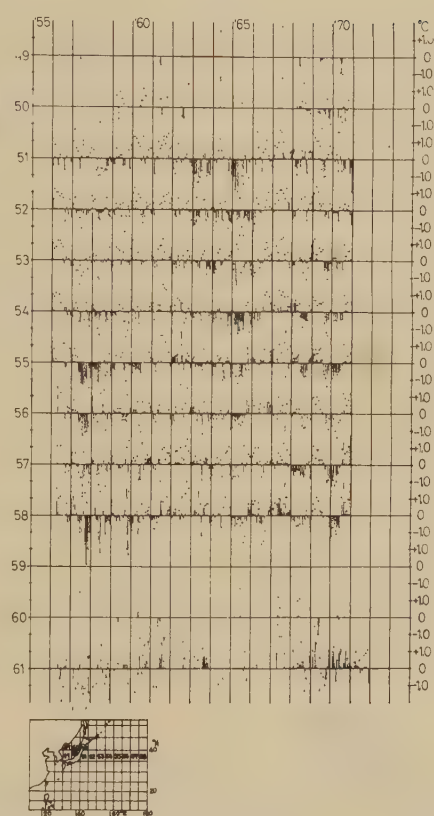


Fig. 5. SST anomalies in the 5 degree blocks, No. 49 to 61.

74 cover the Oyashio area (Figure 7). In general, the change of the anomaly pattern with time is nearly the same as is found in the mixed zone, but superimposed on the general trend, we can also see some short-period changes. Warm periods occurred in the same years as in the northern part of the mixed zone and cold periods in 1957 to 1959, 1964 to 1966 and 1969/70.

From the above-mentioned, we can summarize as follows:

- (i) the change of the anomaly pattern is the same in each of the sea areas south of 25°N, 25° to 35°N, 35° to 45°N and north of 45°N.
- (ii) the amplitude of the change is smallest in the sea south of 35°N (especially small in the area 25° to 35°N and 130° to 175°N), the largest in the mixed zone and next to it is in the Oyashio region.

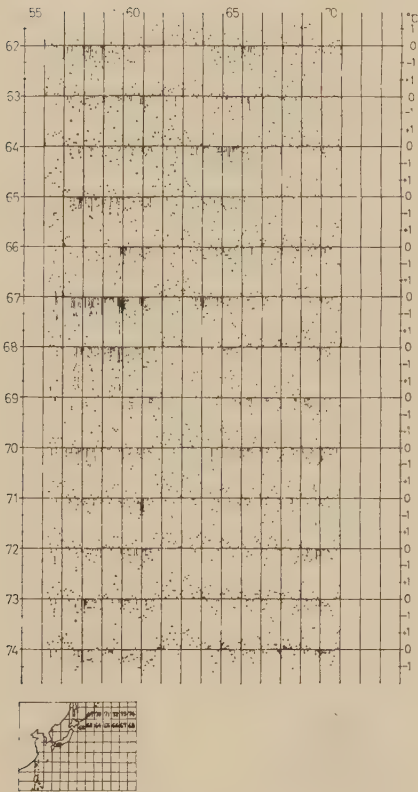


Fig. 6. SST anomalies in the 5 degree blocks, No. 69 to 74.

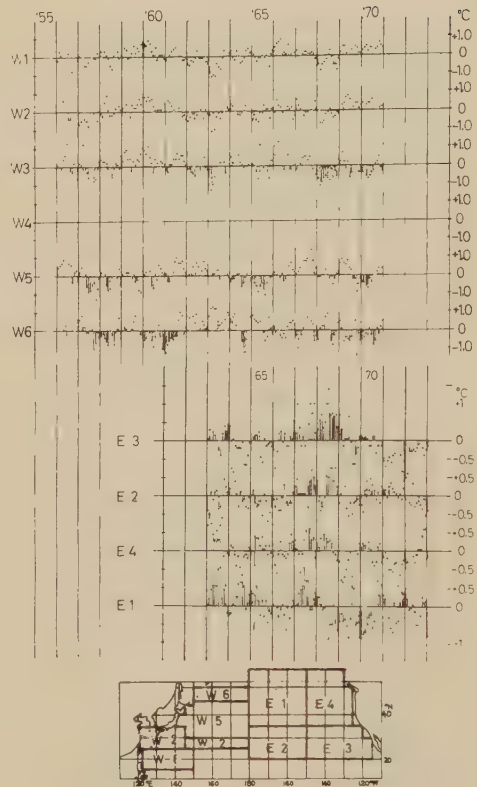


Fig. 7. SST anomalies in the medium blocks; W₁, to W₆ and E₁ to E₄

In figure 7, we have divided the whole area under study into 5 blocks, in order to examine the spatial differences in the patterns of SST change.

(i) Generally speaking, block W₁ shows the same patterns of change as block W₂, and W₅ is the same as W₆. Block W₃ is between them but rather similar to the southern blocks W₁ and W₂.

(ii) In W₁ and W₂ the changes appear to be 1 or 2 years in advance of the corresponding changes found in areas W₅ and W₆. It seems to show the nearly opposite changes between them.

(iii) the southern blocks W₁ and W₂ show the opposite changes to those found in the sea area E₁ to E₄ west of the United State.....so-called see-saw phenomena (Uda, 1960 and Hanzawa, 1960) (see fig. 8 and 9).

	W.N.Pacific						E.N.Pacific			
	W ₁	W ₂	W ₃	W ₅	W ₆		E ₁	E ₂	E ₃	E ₄
1956	+	-	++	++	+					
57	○	○	-	○	-					
58	+	○	○	○	-					
59	+	○	++	○	○					
60	++	○	++	○	○					
61	+	○	○	○	-					
62	-	○	○	○	+					
63	-	○	-	○	++		○	○	++	++
64	○	○	+	○	+		○	○	○	○
65	○	○	○	-	○		+	○	○	○
66	++	○	○	○	○		○	○	○	○
67	○	○	+	+	++		○	○	○	○
68	-	-	-	○	+		○	○	++	++
69	○	+	○	+	+		○	○	○	○
70	+	+	○	-	-		○	○	○	○
71	○	○	○	○	○		+	○	○	○
72	○	○	○	○	○		○	○	○	○
73										

Fig. 8. Brief expression of SST anomalies in the medium blocks
+ or -; within ± 0.5 to ± 1.0 , ++ or --; within ± 1.0
to $\pm 1.5^{\circ}\text{C}$, ○ within $\pm 0.5^{\circ}\text{C}$; ○w oscillation within $\pm 0.5^{\circ}\text{C}$.

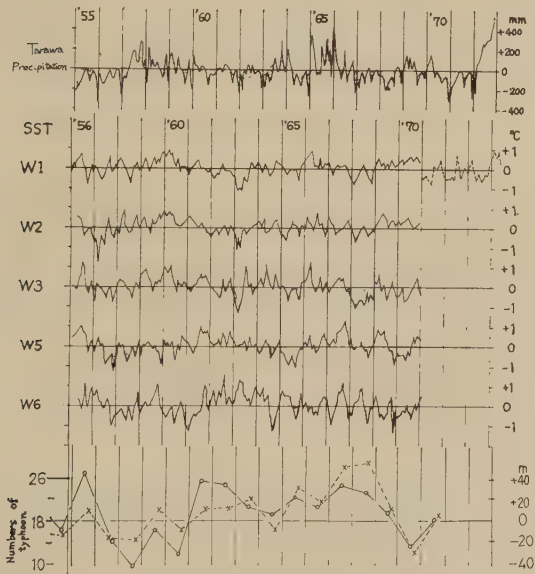


Fig. 9(a) Relation of anomaly of SST to atmospheric phenomena

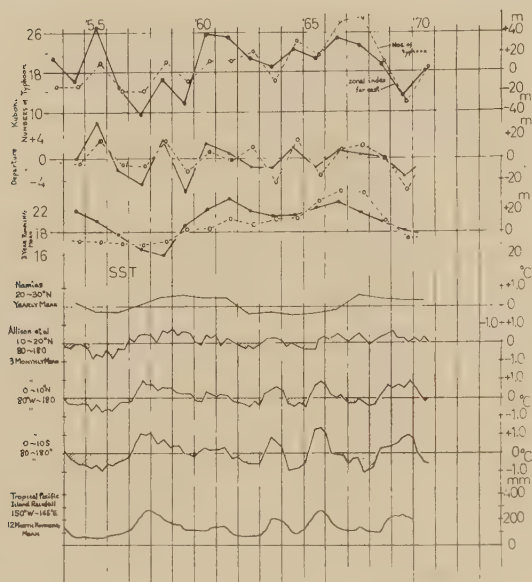


Fig. 9(b) Relation of anomaly of SST to atmospheric and oceanic phenomena

(iv) In W_1 the changes of the anomaly pattern appear to be 1 or 2 years in retardation of the corresponding changes of the precipitation in Tarawa Island, the number of typhoons in autumn in the western North Pacific, 500 mb zonal index in summer in the Far East area, etc. (fig. 9) (KUBOKI, 1971).

(v) Warm eddies from the Kuroshio Extension were especially huge in 1954, 60, 66, and 70.

(vi) MAEDA, et al. (1973) and MATSUYAMA et al. (1973) show that the patterns of changes in the deviations of near-shore temperatures and sea level from their 12-month running means are the same as those found in the offshore areas.

(vii) WYRTKI (1973) shows the sea level differences corresponding to the total mass transport of the Equatorial Counter-Current are well correlated with the changes of SST anomaly in the eastern Pacific. The maxima of the sea level differences used to occur at the same time when the minima of the SST anomaly occurred in the Oyashio and mixed zone.

(viii) As the relating geophysical event, the amplitudes of the annual term of the earth's rotating speed showed abrupt increase of about 0.2 msec in 1958, 1963 and 1969. After the increase they showed gradual decreases (IJIMA, 1973).

(ix) NAITO (1973) discussed the abrupt changes of the mean axis of the earth's

rotation and the Z-term of latitudinal variation in 1953/54, 59/60 and 68/69 and their relations to atmospheric and oceanographical events.

From these, we can tabulate the peaks and troughs in table 1.

Table 1

SST anomaly, Oyashio region, warm	56/57	60-64	67/69	...
SST anomaly, Mixed zone, warm	55/56	60-63	66-69	...
Warm eddy, specially huge	54	60	66	70
Near shore temp., warm (MAEDA et al, 1973)	54/55	60-61	66/67	69
SST anomaly, Kuroshio, warm	56	59-61	66/67	69/70
Sea level, north (Japan), high	54/55	60	66	***
south, high (MATSUYAMA et al, 1973)	54/55	60	***	69
Number of typhoon, many (KUBOKI, 1971)	55	60/61	66/67	...
Zonal index (500mb, far east, 40-60°N), max.	55	61-63	66/67	...
Precipitation, equator, min.	54-56	59-62	67/68	...
Axis of the earth's rotation and Z-term, abrupt change (NAITO, 1973)	53/54	59/60	***	68/69
SST anomaly, Oyashio region, cold	57/58	64-66	69/70	
SST anomaly, mixed zone, cold	57/58	65	69/70	
SST anomaly, Kuroshio region, cold	57	62/63	68	
Number of typhoon, min.	57-59	63	69	
Equatorial C.-Current, max. (WYRTKI, 1973)	57/58	63,65/66	69	
Annual term of the earth's rotation, (IIJIMA, 1973), abrupt change	58	63	69	

*** no corresponding peak, and — no data.

Results of spectral analysis (fig. 10 to 14 and fig. 15)

We used the cyclic Fourier coefficients with the use of the fast Fourier transformation (FFT) instead of autocorrelation functions in order to calculate power spectra, as follows.

$$A_j + B_j i = \sum_{k=0}^{N-1} (X_k + Y_k i) \exp\left(-i \frac{2\pi k j}{N}\right), \quad (j=0, 1, 2, \dots, N-1),$$

and

Power spectrum = $A_j^2 + B_j^2$, ($j=0, 1, 2, \dots, N-1$),

where $i = \sqrt{-1}$ and $X_k + Y_k i$ ($k=0, 1, \dots, N-1$) and a sequence of data (in our case $Y_k=0$), and $A_j + B_j i$, ($j=0, 1, \dots, N-1$) are the Fourier coefficients after Hanning, that is,

$$A_j = -\frac{1}{4} A_{j-1} + \frac{1}{2} A_j - \frac{1}{4} B_{+1},$$

and

$$B_j = -\frac{1}{4} B_{j-1} + \frac{1}{2} B - \frac{1}{4} A_{j+1}, (j=0, 1, 2, \dots, N-1).$$

As the FFT program for computer, we used the one made by Singleton (1969), which is for mixed radix (as the radix we can use the primes 2 to 23). The numbers of our data are 180.....monthly data for 15 years.

(i) Generally speaking, in the sea south of the parallel 35°N, powers of the corresponding significant peaks in each 5-degree square decrease with the distance

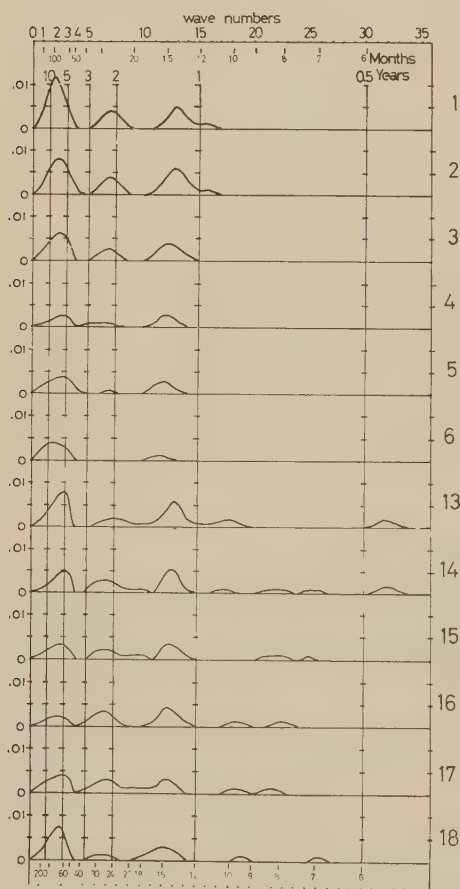


Fig. 10. Spectral densities in the 5 degree blocks, No. 1 to 6 and 13 to 18.

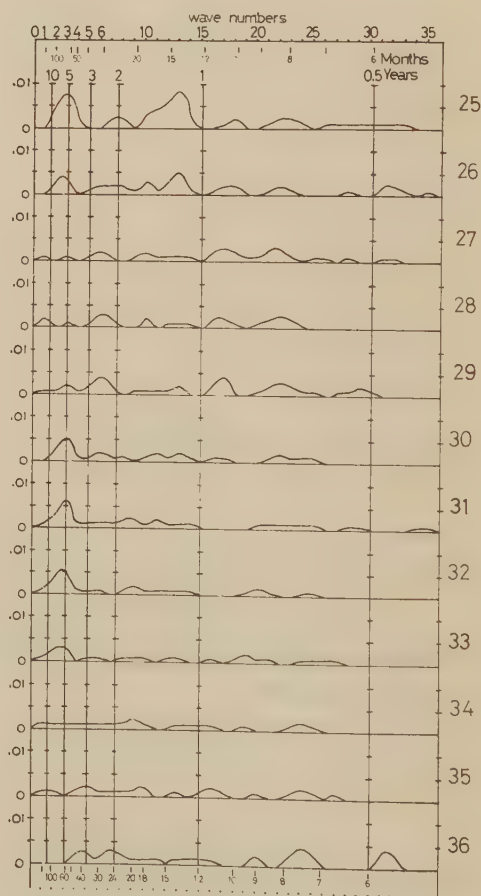


Fig. 11. Spectral densities in the 5 degree blocks, No. 25 to 36.

from the coast, while north of the parallel no special tendency can be found.

(ii) Generally speaking, the spectral peaks at 5- to 7.5-year period are very significant and commonly found in most of the 5-degree blocks. The powers of the peaks are very small in the regions south of 35°N and east of 160°E 5-degree blocks 32 to 36 and 45 to 48, especially weak between 135° and 150°E , while they are very strong in the mixed zone (No. 51 to 58 and No. 62 to 68), Oyashio region (No. 70 to 74), coastal region of the Asian continent (No. 1 to 3, 13 to 15, 25, 26, 37, 38, and 40), and the central part of the sea area considered (No. 30 to 33), especially strong in the mixed zone and the Oyashio region. The peaks do not appear in the 5-degree squares in the zone between 25° and 35°N just inside the Kuroshio (No.

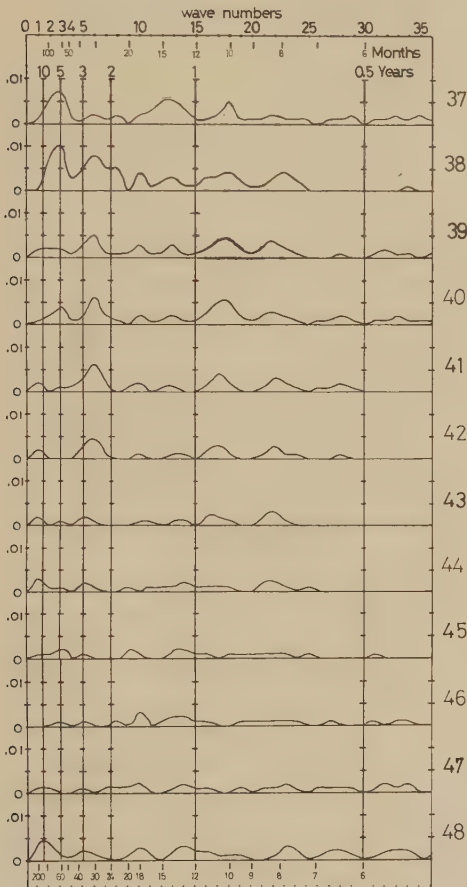


Fig. 12. Spectral densities in the 5 degree blocks, No. 37 to 48.

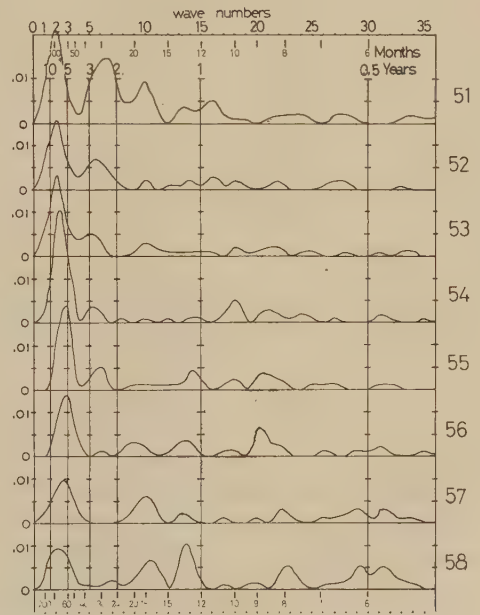


Fig. 13. Spectral densities in the 5 degree blocks, No. 51 to 58.

27 to 29, 34, 35 and 41 to 47) where all the other peaks have weaker power, too.

(iii) Next significant peaks appear at 1- to 1.5-year period and are found in nearly the same regions as the 5- to 7.5-year peaks. In the 5-degree squares No. 6, 31 to 33 and 54, only the 1- to 1.5-year peaks can be found, while in the blocks No. 27 to 29, 39, 41 and 43 to 47 only the 5- to 7.5-year peaks exist.

(iv) The thirdly large peaks situated at 2- to 3-year period, which are very significant in the blocks in the region west of 140°E and between 35° and 40°N, especially significant in the blocks 51 to 56. In the northern part of the mixed

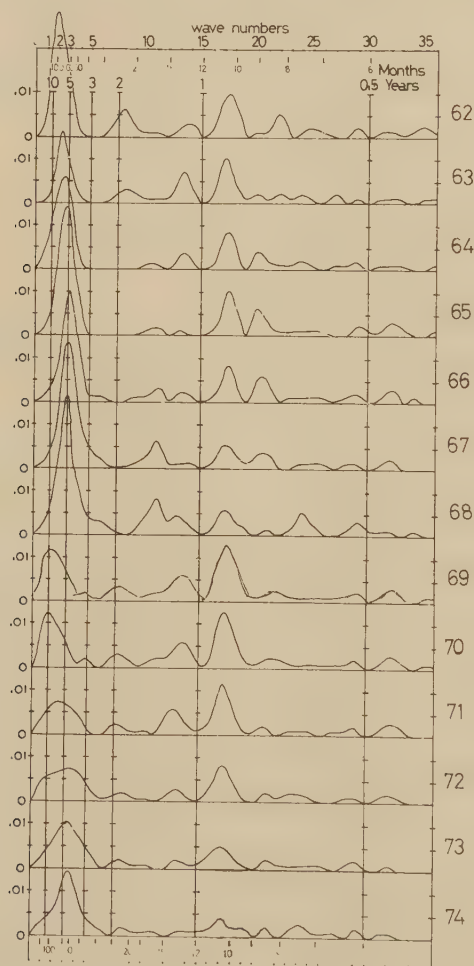


Fig. 14. Spectral densities in the 5 degree blocks, No. 62 to 74.

zone and the Oyashio region, there are no peaks corresponding to this.

(v) Besides the above-mentioned, in many of the 5-degree square spectral peaks are found at 10- to 11-, 8-, 6.5- and 5.5-month period, etc.

The meaning of the above-mentioned peaks is supposed to be some manifestations of the relating change of the atmospheric disturbances, the interaction of the ocean and atmosphere or travelling disturbances out of the regions treated here, etc. The cause will be, however, made clear by more advanced statistical techniques, and physical and theoretical considerations.

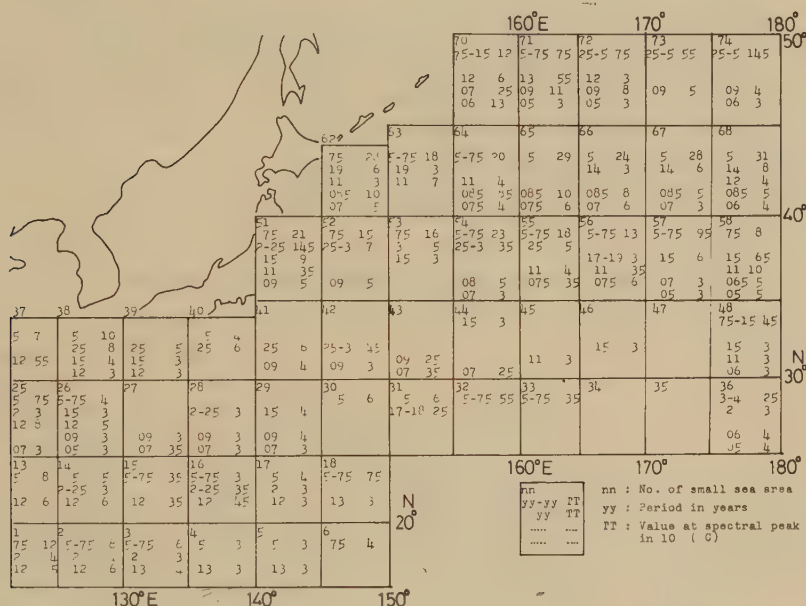


Fig. 15. Brief expression of spectral densities in the 5 degree blocks.

Examples of unusual SST anomaly

(a) Winter of 1963 (fig. 16)

In the winter of 1963 the SST was colder in the western part and warmer in the northern part of the western North Pacific Ocean. In the seas south of Japan and the East China Sea, the anomaly of SST reached nearly -2°C , while in the mixed zone and the Oyashio region, the anomaly was $+1$ to 2°C . This abnormal pattern corresponds well with the atmospheric pressure pattern of the winter..... winter monsoon pattern.

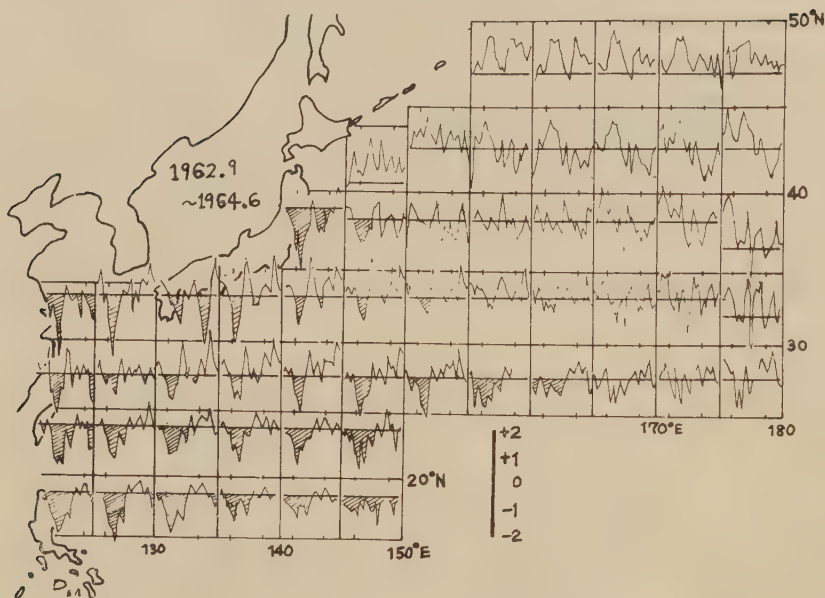


Fig. 16. Example of unusual SST anomaly in 1963

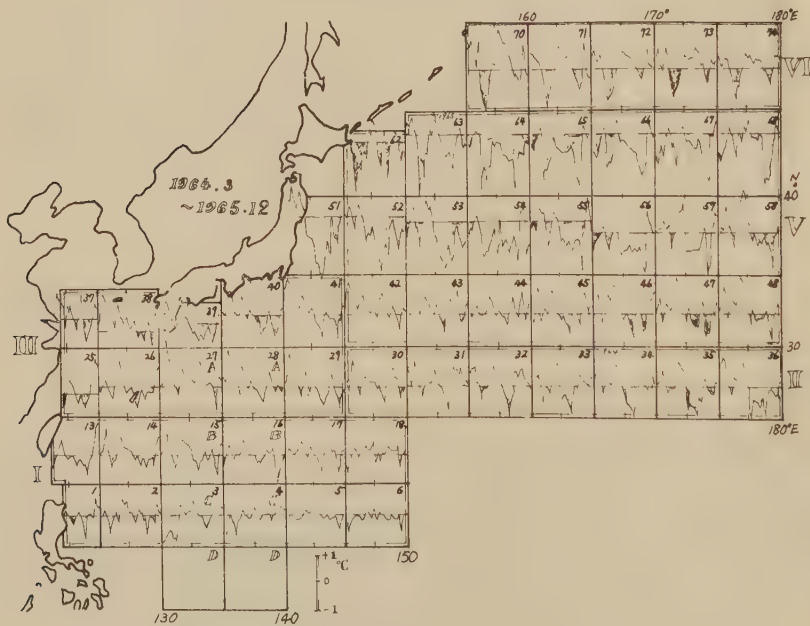


Fig. 17. Example of unusual SST anomaly in 1965

(b) 1965 (fig. 17)

In this year, the anomaly of SST in the mixed zone was less than -2°C , and nearly normal in the sea south of 35°N . It was very cold in the northern hemisphere during the winter and spring of 1965 and a typhoon landed Japan in May, the first time for the past 51 years. Due to the abnormal atmospheric circulation pattern, the northeasterly winds prevailed in the sea east of Japan and transported bulk of cold Oyashio water southwards.

3. Concluding remarks

Analysis of time sequences and spectral analysis of SST anomalies revealed that there is a significant period of about 5 to 7 years which also appears in atmospheric and geophysical events. This fact might show that there is a sort of free mode (with the period of several years) of the entire system of the earth, although the particular processes of the interactions between the ocean and atmosphere, atmosphere and solid earth, etc., are highly nonlinear. From long continued data like coastal temperature, equatorial rainfall, etc., an oscillation with 5 to 7-year periodicity does not continue for long but seems to increase gradually and dies away after three or four peaks.

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西太平洋における海面水温の変動について

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気象庁全国海況旬報より緯経度一度升目の中心水温を 1956~70 年の 15 年について読みとり, これを用いて 5 度升目毎の平均水温を算出し, 偏差の変化傾向を調査した。

偏差変動には大きな傾向がある——即ちどの海域も 4~7 年程度毎に寒暖を繰返している。35° N以南の南方海域と混合水域では位相のずれ, 約一, 二年のおくれが見られ, ほとんど逆の変化をしているように見える。また南方海域の水温変動は, 東部北太平洋の水温と逆の変動を示すことが多い。変動の振巾は 35° ~ 45° N 間——混合水域で大きく, 親潮域がこれに次ぎ, 南方海域が小さくなっている。

スペクトラム解析でも 5~7.5 年, 1~2 年, 10~11 ヶ月, 8 ヶ月, 6.5 ヶ月, 5.5 ヶ月前後の所にピークが見られる。このうち 5~7.5 年のものが全海域に共通で振巾も大きくなっている。

Remarks on the classification of long waves propagating in the marginal sea in a uniformly rotating two-layered ocean

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(Received on Jan. 10, 1974)

Abstract: The possible cases of long waves propagating in a semi-infinite, uniformly rotating two-layered ocean with a single-step bottom topography along the coast, are classified as, (i) the case with a continental shelf the depth of which is less than the thickness of the surface layer, (ii) that with a trough and a surface layer shallower than the depth of the ocean part, (iii) that with a shelf the depth of which is greater than the thickness of the surface layer, and (iv) that with a trough and surface layer deeper than the depth of the ocean part. It is especially interesting that such changes of sea conditions between the cases (i) and (iii), are usually found in the seas south to southwest of Japan where the warm Kuroshio water is flowing

1. Introduction

In the ocean with uniform depth on the rotating system, long waves can propagate in a direction with the coast to the right in the northern hemisphere and with the amplitude decreasing exponentially with a distance from the coast (Kelvin, 1879). It is also known that in the non-rotating ocean waves can propagate in both directions along the coast but some of them have amplitudes decreasing with the distance from the coast when the depth of the ocean or the thickness of the water layer changes with the distance from the coast (Snodgrass et al, 1962 and Sezawa et al, 1939). These facts show that the shores on the earth act as wave guides by the effects of the rotation of the system and/or the changes of the thickness of the water layers or the depth. The wave guide effects are very important for the problems on the propagation of tidal waves, the response of the marginal seas for atmospheric disturbances, and so on.

Density stratification of water as well as the change of depth near the coast becomes important for the above-mentioned problems and those on internal waves

near the coast.

In this paper, the marginal seas with abrupt depth changes—a continental shelf or trench along the coast, are treated for two-layered water on the rotating system.

The equations of motion and continuity in such a two-layered ocean are as,

$$\frac{\partial u_1}{\partial t} - f v_1 = -g \frac{\partial \zeta_1}{\partial x}, \quad (1-1)$$

$$\frac{\partial v_1}{\partial t} + f u_1 = -g \frac{\partial \zeta_1}{\partial y}, \quad (1-2)$$

and

$$h_1 \frac{\partial u_1}{\partial x} + h_1 \frac{\partial v_1}{\partial y} = \frac{\partial \zeta_2}{\partial t} - \frac{\partial \zeta_1}{\partial t} \quad (1-3)$$

for the upper layer and

$$\frac{\partial u_2}{\partial t} - f v_2 = -g \frac{\partial}{\partial x} (\gamma \zeta_1 + \delta \zeta_2), \quad (1-4)$$

$$\frac{\partial v_2}{\partial t} + f u_2 = -g \frac{\partial}{\partial y} (\gamma \zeta_1 + \delta \zeta_2), \quad (1-5)$$

and

$$h_2 \frac{\partial u_2}{\partial x} + h_2 \frac{\partial v_2}{\partial y} = -\frac{\partial \zeta_2}{\partial t}, \quad (1-6)$$

for the lower layer, where $\gamma = \rho_1 / \rho_2$ and $\delta = \Delta \rho / \rho_2 = (\rho_2 - \rho_1) / \rho_2$, f , g , u_i , v_i , h_i , ρ_i and ζ_i are the Coriolis parameter, gravitational acceleration, x -components of velocity, y -components of velocity, thickness, densities of the upper layer for $i=1$ and the lower layer for $i=2$, and displacements of the surface for $i=1$ and the interface for $i=2$. The same equations hold both on the shelf and in the open ocean, where u_i , v_i , ζ_i , and h_i should be replaced by u_i' , v_i' , ζ_i' , and h_i' . The boundary conditions for them are:

$$h_i u_i = h_i' u_i' \quad \text{at } x=0, \quad (1-7)$$

$$u_i = 0 \quad \text{at } x=L, \quad i=1, 2 \quad (1-8)$$

$$\zeta_i = \zeta_i' \quad \text{at } x=L \quad (1-9)$$

and u_i' , v_i' , and ζ_i' are finite at infinity.

The solutions of equations (1-1) to (1-6) can be assumed as follows:

$$u_i = a_i S(x) \sin(\sigma t + k y + \phi), \quad (1-10)$$

$$v_i = (b_i C(x) + c_i S(x)) \cos(\sigma t + k y + \phi), \quad (1-11)$$

$$\text{and} \quad \zeta_i = (d_i C(x) + e_i S(x)) \cos(\sigma t + k y + \phi), \quad (1-12)$$

where

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$$S(x) = \sin(nx) \quad \text{or} \quad \sinh(nx) \quad \text{for the shelf part, and} \\ = \sin(n'x + \beta) \quad \text{or} \quad \exp(-n'x) \quad \text{for the ocean part,}$$

and

$$C(x) = \cos(nx) \quad \text{or} \quad \cosh(nx) \quad \text{for the shelf part, and} \\ = \cos(n'x + \beta) \quad \text{or} \quad 0 \quad \text{for the ocean part,}$$

and a 's, b 's, c 's, d 's, e 's, β and ϕ are constant, σ and k are the frequency and y -component of wave number, respectively, and n 's are parameters or x -components of wave number.

The corresponding frequency equation becomes,

$$\delta g^2 h_1 h_2 (k^2 \pm n^2) + g(h_1 + h_2)(k^2 \pm n^2)(f^2 - \sigma^2) + (f^2 - \sigma^2)^2 = 0 \quad (1-13)$$

where $+$ sign corresponds to leaky mode (spherical harmonics) and $-$ sign to trapped mode (hyperbolic functions). In the open ocean h_1 , h_2 , and n must be replaced by h_1' , h_2' , and n' .

When the density difference is very small, $\delta \ll 1$, equation (1-1) can be divided as follows:

$$\frac{f^2 - \sigma^2}{k^2 \pm n^2} \sim -Cs^2 + C_I^2, \quad (1-14)$$

or

$$\sim -C_I^2 - C_I^4 / Cs^2, \quad (1-15)$$

where

$$Cs = \sqrt{g(h_1 + h_2)} \quad \text{and} \quad C_I = \sqrt{\delta g h_1 h_2 (h_1 + h_2)} \quad \text{and} \quad Cs \gg C_I.$$

The ratio of the amplitude of surface deviation to that of interface is $(h_1 + h_2)/h_2$ for equation (1-14) and δ for (1-15). The motions in the system are, therefore, divided almost perfectly into two regimes, that is, barotropic or surface mode for equation (1-14) and baroclinic or internal mode for (1-15). The corresponding n 's will be expressed as n_S and n_I .

Leaky mode solutions can be expressed as,

$$\left. \begin{aligned} u_i^k &= a_i^k \sin(n_k x) \sin \phi, \\ v_i^k &= (b_i^k \cos(n_k x) + c_i^k \sin(n_k x)) \cdot \cos \phi, \\ i &= 1 \text{ (for the surface layer) or } i = 2 \text{ (for the lower} \\ &\text{layer) and } k = S \text{ (for surface mode) or } k = I \text{ (for} \\ &\text{internal mode)} \end{aligned} \right\} \quad (1-16)$$

and

$$\zeta_i^k = (d_i^k \cos(n_k x) + e_i^k \sin(n_k x)) \cdot \cos \phi,$$

for the shelf part, and the same type of solutions hold for the open ocean part, where u_i^k , v_i^k , ζ_i^k , a_i^k , b_i^k , c_i^k , d_i^k , e_i^k , n_k and $n_k x$ should be replaced by $u_i^{k'}$, $v_i^{k'}$, $\zeta_i^{k'}$, $a_i^{k'}$, $b_i^{k'}$, $c_i^{k'}$, $d_i^{k'}$, $e_i^{k'}$, $n_{k'}$ and $(n_{k'}x + \beta)$, respectively. Trapped mode solutions are expressed as,

$$\left. \begin{aligned} u_i^k &= a_i^k \sinh(n_k x) \cdot \sin \phi, \\ v_i^k &= (b_i^k \cosh(n_k x) + c_i^k \sinh(n_k x)) \cdot \cos \phi, \\ i &= 1 \text{ or } i = 2 \text{ and } k = S \text{ or } k = I \end{aligned} \right\} \quad (1-17)$$

and

$$\zeta_i^k = (d_i^k \cosh(n_k x) + e_i^k \sinh(n_k x)) \cdot \cos \phi$$

on the shelf or the trench. The coefficients of equations (1-16) and (1-17) are

$$\left. \begin{aligned} \phi &= ky + \sigma t + \psi, \\ a_1^k &= -\frac{g}{n_k \sigma} \frac{f^2 k^2 \pm \sigma^2 n_k^2}{f^2 - \sigma^2} d_1^k, \\ b_1^k &= -\frac{g}{n_k \sigma} d_1^k, \\ c_1^k &= -\frac{gf}{n_k} \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} d_1^k, \\ e_1^k &= -\frac{fk}{n_k \sigma} d_1^k, \\ a_2^k &= -\frac{g}{n_k \sigma} \frac{f^2 k^2 \pm \sigma^2 n_k^2}{f^2 - \sigma^2} \left(1 + \delta g h_1 \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \right) d_1^k, \\ b_2^k &= -\frac{gk}{n_k \sigma} \left(1 + \delta g h_1 \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \right) d_1^k, \\ c_2^k &= -\frac{gf}{n_k} \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \left(1 + \delta g h_1 \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \right) d_1^k, \\ d_2^k &= -\left(1 + g h_1 \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \right) d_1^k, \\ e_1^k &= -\frac{fk}{n_k \sigma} \left(1 + g h_1 \frac{k^2 \pm n_k^2}{f^2 - \sigma^2} \right) d_1^k, \end{aligned} \right\} \quad (1-18)$$

where + sign corresponds to those for eq. (1-16) and - sign to those for eq. (1-17),

Trapped mode solutions in the open ocean are:

$$\left. \begin{aligned} u_i^{k'} &= a_i^{k'} \exp(-n_{k'} x) \sin \phi, \\ v_i^{k'} &= b_i^{k'} \exp(-n_{k'} x) \cos \phi, \\ \zeta_i^{k'} &= d_i^{k'} \exp(-n_{k'} x) \cos \phi, \end{aligned} \right\} \begin{array}{l} i = 1 \text{ or } i = 2 \text{ and} \\ k = S \text{ or } k = I \end{array} \quad (1-19)$$

and

where

$$\begin{aligned}
 a_1^{k'} &= \frac{g(fk - n_k' \sigma)}{f^2 - \sigma^2} d_1^{k'}, \\
 b_1^{k'} &= \frac{g(\sigma k - n_k' f)}{f^2 - \sigma^2} d_1^{k'}, \\
 a_2^{k'} &= \frac{g(fk - n_k' \sigma)}{f^2 - \sigma^2} \left(1 + \delta g h_1' \frac{k^2 - n_k'^2}{f^2 - \sigma^2} \right) d_1^{k'}, \\
 b_2^{k'} &= \frac{g(\sigma k - n_k' f)}{f^2 - \sigma^2} \left(1 + \delta g h_1' \frac{k^2 - n_k'^2}{f^2 - \sigma^2} \right) d_1^{k'}, \\
 \text{and} \quad d_2^{k'} &= g \left(1 + \frac{k^2 - n_k'^2}{f^2 - \sigma^2} g h_1' \right) d_1^{k'}.
 \end{aligned} \tag{1-20}$$

2. Classification of motions

RATTRAY (1960) treated the problems on the response of the water on the shelf to long waves incident normally to the coast and found that the generated internal tides become larger in amplitude at some wave lengths of incident long waves. The problems for the glanced incidence of long waves to the coast in the same system were studied by ICHIYE (1963). These investigations are concerning with long waves of frequencies larger than the Coriolis parameter in a two-layer ocean with a continental shelf the depth of which is constant or nearly constant and larger than the thickness of the upper layer.

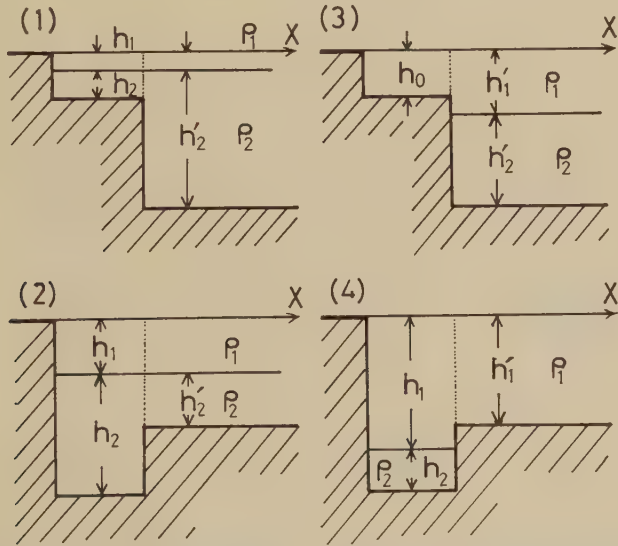


Fig. 1. Four cases of single-step bottom topography along the coast,

In general, the following four cases can be distinguished in the point of the relation between the depth of the ocean or the continental shelf and the thickness of the upper layer.

(a-1) Marginal sea with a continental shelf the depth of which is larger than the thickness of the upper layer (fig. 1-1).

The solutions of equations of motion can be expressed by the combinations of $\sinh nx$ and $\cosh nx$, or $\sin nx$ and $\cos nx$ on the shelf or trench and as that of $\exp(-nx)$, or $\sin nx$ and $\cos nx$ in the open ocean, multiplied by a factor, $\sin$ or $\cos(k'y + \sigma t + \psi)$, where the x - and y -axes point seawards and with the coast to the left, respectively. Those combinations are shown in Table 1-1, where leaky mode means the solution contains a factor, $\sin nx$ and/or $\cos nx$, and trapped mode means the solution contains a factor, $\sinh nx$ and/or $\cosh nx$ for the shelf or trench part and $\exp(-nx)$ for the open ocean part, and in the range of frequency, $|\sigma| > f$, k_s , k'_s , k_I , and k'_I are defined by,

$$k_s \cong \sqrt{(\sigma^2 - f^2)/g(h_1 + h_2)}, \quad (2-1)$$

$$k'_s \cong \sqrt{(\sigma^2 - f^2)/g(h_1 + h'_2)}, \quad (2-2)$$

$$k_I \cong \sqrt{(\sigma^2 - f^2)/\{\delta gh_1 h_2/(h_1 + h_2)\}} \quad (2-3)$$

and

$$k'_I \cong \sqrt{(\sigma^2 - f^2)/\{\delta gh_1 h'_2/(h_1 + h'_2)\}}, \quad (2-4)$$

where h'_2 is the thickness of the lower layer in the open ocean as shown in figure 1-1.

Table 1-1. Combination of solutions.

Range of Frequency	Range of Wave Number	Solution on the Shelf		Solution in the Open Ocean	
		Internal Mode	Surface Mode	Internal Mode	Surface Mode
$\sigma^2 > f^2$	$k'_s \geq k$	Leaky	Leaky	Leaky	Leaky
	$k_s \geq k > k'_s$	Leaky	Leaky	Leaky	Trapped
	$k'_I \geq k > k_s$	Leaky	Trapped	Leaky	Trapped
	$k_I \geq k > k'_I$	Leaky	Trapped	Trapped	Trapped
	$k > k_I$	Trapped	Trapped	Trapped	Trapped
$\sigma^2 = f^2$					
$\sigma^2 < f^2$		Trapped	Trapped	Trapped	Trapped

(a-2) Marginal sea with a trough along the coast and the thickness of the upper layer is smaller than the depth of the open ocean.

H. IIDA: Classification of long waves in the marginal sea

For the case shown in figure 1-2, the combinations of solutions are listed in Table 1-2. where k_I , k_I' , k_S and k_S' are the same as those in (a-1) and $k_I' > k_I > k_S' > k_S$.

Table 1-2. Combinations of solutions.

Range of Frequency	Range of Wave Number	Solution on the Shelf		Solution in the Open Ocean	
		Internal Mode	Surface Mode	Internal Mode	Surface Mode
$\sigma^2 > f^2$	$k_S \geq k$	Leaky	Leaky	Leaky	Leaky
	$k_S' \geq k > k_S$	Leaky	Trapped	Leaky	Leaky
	$k_I \geq k > k_S'$	Leaky	Trapped	Leaky	Trapped
	$k_I' \geq k > k_I$	Leaky	Trapped	Trapped	Trapped
	$k > k_I'$	Trapped	Trapped	Trapped	Trapped
$\sigma^2 = f^2$					
$\sigma^2 < f^2$		Trapped	Trapped	Trapped	Trapped

(a-3) Marginal sea with a continental shelf the depth of which is smaller than the thickness of the upper layer (figure 1-3).

In this case the solutions of the equations of motion for the shelf part contain no internal mode and the corresponding frequency equation becomes,

$$\frac{f^2 - \sigma^2}{\pm n_0^2 + k^2} + gh_1 = 0. \quad (2-5)$$

The combinations of solutions are shown in table 1-3, where $k_0 = \sqrt{(\sigma^2 - f^2)/gh_1}$ for $|\sigma| > f$ and k_S' and k_I' are expressed by,

$$k_S' = \sqrt{\{g(h_1' + h_2')\}^{-1}(\sigma^2 - f^2)}, \quad (2-6)$$

and

$$k_I' = \sqrt{\{\partial gh_1' h_2' / (h_1' + h_2')\}^{-1}(\sigma^2 - f^2)}, \quad (2-7)$$

where h_1' and h_2' are the thickness of the upper and lower layer in the open ocean.

In case $k_S' > k$ and $|\sigma| > f$, the motion of the system is expressed as,

$$\begin{aligned} u_i &= (a_i^S \sin(n_S x) + a_i^I \sin(n_I x)) \cdot \sin \phi, \\ v_i &= (b_i^S \cos(n_S x) + c_i^S \sin(n_S x) + b_i^I \cos(n_I x) \\ &\quad + c_i^I \sin(n_I x)) \cdot \cos \phi, \end{aligned} \quad \begin{matrix} i = 1 \text{ or} \\ i = 2 \end{matrix} \quad (2-8)$$

and

$$\begin{aligned} \zeta_i &= (d_i^S \cos(n_S x) + e_i^S \sin(n_S x) + d_i^I \cos(n_I x) \\ &\quad + e_i^I \sin(n_I x)) \cos \phi, \end{aligned}$$

for $0 \leq x < L$, and the solutions of the same form hold for $L \leq x$, where the constants

$a_i^k, b_i^k, c_i^k, d_i^k, e_i^k, n_k$ and $n_k x$ should be changed into $a_i^{k'}, b_i^{k'}, c_i^{k'}, d_i^{k'}, e_i^{k'}, n_k' x$ and $n_k' x + \beta_k$.

All the coefficients a_i^k to e_i^k and $a_i^{k'}$ to $e_i^{k'}$ are expressed in terms of the 6 constants, $d_i^S, d_i^I, d_i^{S'}, d_i^{I'}, \beta_S$ and β_I . The four relations concerning the 6 constants are obtained from the boundary conditions at $x=L$. The system of the relations is homogeneous and linear concerning the four d 's so the condition that the determinant should be equal to 0, determines the relation between β_S and β_I . For the range of frequencies and wave numbers, the free modes of the system have continuous spectrum.

Considering the case, $k_I \geq k \geq k'_I$ and $|\sigma| > f$, as another example, only the internal mode on the shelf is leaky, so the solutions of the system are:

$$\begin{aligned} u_i &= (a_i^S \sinh(n_S x) + a_i^I \sin(n_I x)) \cdot \sin \phi, \\ v_i &= (b_i^S \cosh(n_S x) + c_i^S \sinh(n_S x) + b_i^I \cos(n_I x) \\ &\quad + c_i^I \sin(n_I x)) \cdot \cos \phi, \end{aligned} \quad \begin{array}{l} i = 1 \text{ or} \\ i = 2 \end{array} \quad (2-9)$$

and

$$\begin{aligned} \zeta_i &= (d_i^S \cosh(n_S x) + e_i^S \sinh(n_S x) + d_i^I \cos(n_I x) \\ &\quad + e_i^I \sin(n_I x)) \cdot \cos \phi, \end{aligned}$$

for $0 \leq x < L$, and

$$\begin{aligned} u'_i &= (a_i^{S'} \exp(-n'_S x) + a_i^{I'} \exp(-n'_I x)) \cdot \sin \phi, \\ v'_i &= (b_i^{S'} \exp(-n'_S x) + b_i^{I'} \exp(-n'_I x)) \cdot \cos \phi, \end{aligned} \quad \begin{array}{l} i = 1 \text{ or} \\ i = 2 \end{array} \quad (2-10)$$

and

$$\zeta'_i = (d_i^{S'} \exp(-n'_S x) + d_i^{I'} \exp(-n'_I x)) \cdot \cos \phi,$$

for $x \geq L$.

The determinant for the system of homogeneous linear equations on $d_i^S, d_i^I, d_i^{S'}$ and $d_i^{I'}$, contains no constant parameters to be determined, so the system is unsolvable, except k and σ which have special relations. In this range of frequencies and wave numbers, the free modes of the system have discrete spectrum.

In this case there is no internal mode on the shelf and the boundary conditions at the margin of the continental shelf, $x=L$, become,

$$\begin{aligned} h_1 u_1 &= h'_1 u'_1, \\ 0 &= h'_2 u'_2, \end{aligned} \quad (2-11)$$

and

$$\zeta_1 = \zeta'_1$$

The solutions on the shelf are:

$$\begin{aligned} u &= a \cdot \sin(n_0 x) \cdot \sin \phi, \\ v &= (b \cdot \cos(n_0 x) + c \cdot \sin(n_0 x)) \cdot \cos \phi, \end{aligned} \quad (2-12)$$

and

$$\zeta = (d \cdot \cos(n_0 x) + e \cdot \sin(n_0 x)) \cdot \cos \phi,$$

for leaky mode and

$$\begin{aligned} u &= a \cdot \sinh(n_0 x) \cdot \sin \phi, \\ v &= (b \cdot \cosh(n_0 x) + c \cdot \sinh(n_0 x)) \cdot \cos \phi, \end{aligned} \quad (2-13)$$

and $\zeta = (d \cdot \cosh(n_0 x) + e \cdot \sinh(n_0 x)) \cdot \cos \phi$,

for trapped mode, where $\phi = ky + \sigma t + \phi$ and

$$\begin{aligned} a &= -\frac{g}{n_0 \sigma} \frac{\pm n_0^2 \sigma^2 + f^2 k^2}{f^2 - \sigma^2} d, \\ b &= -\frac{gk}{\sigma} d, \\ c &= -\frac{fg}{n_0} \frac{k^2 \pm n_0^2}{f^2 - \sigma^2} d, \\ \text{and} \quad e &= -\frac{fg}{n_0 \sigma} d, \end{aligned} \quad (2-14)$$

(-sign for leaky mode and + for trapped mode). In the open sea, the same solutions as those in the previous paragraphs hold.

From the boundary conditions (2-11), a system of three homogeneous linear equations concerning d , $d_1^{S'}$ and $d_2^{S'}$ is obtained, and the condition that the system has no trivial solutions determines the dispersive relation, etc. as before.

In case, $k'_S \geq k$ and $|\sigma| > f$, as example, the system of homogeneous linear equations becomes as follows:

$$\begin{aligned} ah_1 \cdot \sin(n_0 L) &= h'_1 (a_1^{S'} \sin(n'_S L + \beta_S) + a_1^{I'} \sin(n'_I L + \beta_I)), \\ 0 &= h'_2 (a_2^{S'} \sin(n'_S L + \beta_S) + a_2^{I'} \sin(n'_I L + \beta_I)), \end{aligned} \quad (2-15)$$

and

$$\begin{aligned} d \cdot \cos(n_0 L) + e \cdot \sin(n_0 L) &= (d_1^{S'} \cos(n'_S L + \beta_S) + e_1^{S'} \sin(n'_S L + \beta_S) \\ &+ d_1^{I'} \cos(n'_I L + \beta_I) + e_1^{I'} \sin(n'_I L + \beta_I)), \end{aligned}$$

The condition that the determinant is equal to 0, gives a relation between β_S and β_I , and the spectrum of the system is continuous.

As another example, in case $k \geq k_I$, the system of equations is,

$$\begin{aligned} ah_1 \cdot \sinh(n_0 L) &= h'_1 (a_1^{S'} \exp(-n'_S L) + a_1^{I'} \exp(-n'_I L)), \\ 0 &= h'_2 (a_2^{S'} \exp(-n'_S L) + a_2^{I'} \exp(-n'_I L)), \end{aligned} \quad (2-16)$$

and

$$d \cdot \cosh(n_0 L) + e \cdot \sinh(n_0 L) = d_1^{S'} \exp(-n'_S L) + d_1^{I'} \exp(-n'_I L).$$

The determinant gives the dispersive relation.

When $h < \delta h'_2 / (1 + h'_1 / h'_2)$, $k'_S < k'_0 < k'_I$, so k_0 and k'_I should be exchanged and the corresponding modes must be changed in Table 1-3.

(a-4) Marginal sea with a trench along the coast and the depth of the open ocean is smaller than the thickness of the upper layer in the trench region.

Table 1-3. Combination of solutions for $h_1 > \delta h' / (1 + h_1' / h_1'2)$.

Range of Frequency	Range of Wave Number	Solution on the Shelf		Solution in the Open Ocean	
		Internal Mode	Surface Mode	Internal Mode	Surface Mode
$\sigma^2 > f^2$	$k'_s \geq k$	—	Leaky	Leaky	Leaky
	$k_0 \geq k > k'_s$	—	Leaky	Leaky	Trapped
	$k_I \geq k > k'_0$	—	Trapped	Leaky	Trapped
	$k > k'_I$	—	Trapped	Trapped	Trapped
$\sigma^2 = f^2$					
$\sigma^2 < f^2$		—	Trapped	Trapped	Trapped

Table 1-4. Combination of solutions for $h'_1 > \delta h_2 / (1 + h_1 / h_2)$.

Range of Frequency	Range of Wave Number	Solution on the Shelf		Solution in the Open Ocean	
		Internal Mode	Surface Mode	Internal Mode	Surface Mode
$\sigma^2 > f^2$	$k_s \geq k$	Leaky	Leaky	—	Leaky
	$k'_0 \geq k > k_s$	Leaky	Trapped	—	Leaky
	$k_I \geq k > k'_0$	Leaky	Trapped	—	Trapped
	$x > k_I$	Trapped	Trapped	—	Trapped
$\sigma^2 = f^2$					
$\sigma^2 < f^2$		Trapped	Trapped	—	Trapped

The combinations of the solutions are in Table 1-4, where $k'_0 = \sqrt{(\sigma^2 - f^2) / gh'}$. As k'_0 becomes the largest and k_I next to it for the case $h'_1 < \delta h_2 / (1 + h_1 / h_2)$, the same kind of exchanges as in (a-3) should be added to Table 1-4.

In the above-mentioned classifications, k_s , k_I , k'_s , or k'_I is the critical value of wave number k above which the corresponding mode becomes trapped and below which it remains leaky. For example, when $k > k_s$, the surface mode on the shelf becomes trapped and when $k > k'_I$ the internal mode in the open sea becomes trapped, etc. Therefore, when k is larger than the largest among the critical wave numbers, all the modes of the wave motions in the system become trapped for the range of frequency, $\sigma^2 > f^2$. For $\sigma^2 < f^2$, the modes must be trapped ones in the whole range of wave number, k . When the modes are trapped ones, the spectrum of free modes is discrete.

3 Remarks

Among the four cases treated in the previous section, the cases (a-1) and (a-3) are especially interesting from the view point of analysing tidal phenomena, sea level anomaly, behaviors of long waves, etc. on the shelf. The response of the marginal waters to atmospheric disturbances and incident or travelling long waves might be very different depending on whether warm water covers the whole layers on the shelf or there are two layers of water, that is, the thickness of the warmer water is shallower than the depth of continental shelf. The analyses of the whole cases are left for future.

LARSEN (1969) treated problems on long waves along a single-step topography in a semi-infinite uniformly rotating homogeneous ocean. In our case (a-3), we get the following relation for $k > k'_I$ and $|\sigma| > f$ or all k 's and $\sigma < f$, from equations (2-17),

$$\varepsilon(f^2k^2 - n_0^2\sigma^2)\{\sigma(n'_I - n'_S)(\Delta - \delta gh'_1k^2) + fk\xi\Delta + \sigma(n'_S^3 - n'_I^3)\delta gh'_1\} \\ + \xi\left(\coth(n_0L) - \frac{fk}{\sigma n_0}\right)(fk - n'_S\sigma)(fk - n'_I)\Delta n_0\sigma = 0, \quad (3-1)$$

where

$$n_0^2 = k^2 + \frac{f^2 - \sigma^2}{gh_1} \\ n'_S{}^2 = k^2 + \frac{g(h'_1 + h'_2)}{f^2 - \sigma^2} \\ n'_I{}^2 = k^2 + \frac{f^2 - \sigma^2}{\delta gh'_1h'_2/(h'_1 + h'_2)}$$

and $\Delta = f^2 - \sigma^2$, $\xi = (h'_1 + h'_2)/h'_2$ and $\varepsilon = h_1/h'_1$, and h_1 , h'_1 and h'_2 are the depths of water layers on the shelf, upper layer and lower layer in the ocean, respectively. When $k > k_0$ or k'_S , n_0 and n'_S are nearly equal to k . The relation (3-1) becomes,

$$n'_I\sigma\{\sigma\xi(\coth(kL) - f/\sigma) - (f + \sigma)\varepsilon\Delta \\ + k\{\varepsilon(1 - \xi)\sigma(f + \sigma) - \xi\varepsilon\Delta - \xi f\sigma(\coth(kL) - f/\sigma)\} = 0, \quad (3-2)$$

which becomes

$$n'_I\sigma\{\sigma\xi(1 - f/\sigma) + \varepsilon(\xi - 1)(f + \sigma)\} \\ + k\{\varepsilon(\sigma - \xi f)(f + \sigma) - \xi f\sigma(1 - f/\sigma)\} = 0, \quad (3-3)$$

for $kL > 1$. In this case we can obtain dispersive relations for limiting cases,

$$\sigma \sim f \frac{\xi - \varepsilon(\xi - 1)}{\xi + \varepsilon(\xi - 1)} \sim f \frac{h'_1 + h'_2 - h_1}{h'_1 + h'_2 + h_1}, \quad (3-4)$$

for $k^2 \gg |(\sigma^2 - f^2)|/C_I'^2$, and

$$\sigma \sim f \frac{1-\varepsilon}{1+\varepsilon} \sim f \frac{h'_1 - h_1}{h'_1 + h_1}, \quad (3-5)$$

for $k^2 \ll |(\sigma^2 - f^2)|/C_l'^2$. The former one is barotropic quasi-geostrophic as treated by Larsen.

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回転している 2 層海洋の海岸附近を伝わる波の分類について

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半無限の階段状の水深変化がある海岸附近を伝わる長波の可能な場合を分類した。(i) 大陸棚も大洋中もともに 2 層からなる, (ii) 岸に沿って海溝があり, そこでも大洋上でも, とともに 2 層からなる, (iii) 上層の厚さが大陸棚の深さより小さい, および, (iv) 海溝上は 2 層で大洋上は 1 層からなる——4 つの場合がある。このうち (i) と (iii) がとくに我々の注目を惹くものである。日本の南沖, および東支那海の大陸棚縁辺部では上層に相当する黒潮系暖水が (i) および (iii) の状態の変化を繰返えすことが多い。

The Cadmium content in sea water in the adjacent regions of Japan and in the western North Pacific

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(Received on Jan. 20, 1974)

Abstract: Dithizone extraction method has been applied to the measurement of the trace amount of cadmium in sea water at the content level of $0.01\mu\text{g/l}$. The average content of cadmium in 66 surface water samples is $0.06\mu\text{g/l}$ ranging from 0.00 to $0.65\mu\text{g/l}$. The average in deep water samples at about 1,000m depth is $0.11\mu\text{g/l}$ which is significantly higher than that in surface waters.

1. Introduction

It has been urgently requested to survey the background level of chemical substances in sea water in connection with the environmental pollution. In response to the request, the Japan Meteorological Agency initiated the basic marine pollution survey in 1972. Cadmium is one of the most harmful pollutants in the marine environment together with lead and mercury.

In recent years, the atomic absorption spectrophotometry has currently offered the best analytical technique for the detection of trace amounts of metals. However, a preliminary concentration of the cadmium in sample water is necessary, since the cadmium content in sea water of the open ocean is generally below the limit of direct detection of the atomic absorption spectrophotometry. For the concentration of cadmium in solutions the following methods have been applied; the method of solvent extraction (YAMAMOTO, 1971: APDC-MIBK, Dithizone-carbon tetrachloride or -nitrobenzene, etc), precipitation of cadmium as sulfide (ISHIBASHI et al, 1962) and the ion exchange on resin (BIECHLER, 1965; SUGIMURA, 1966). In the present work, the method of back extraction with hydrochloric acid after dithizone-carbon tetrachloride extraction was applied for the concentration of the cadmium. Contents of cadmium in sea water measured in the adjacent regions of Japan and in the western North Pacific are reported.

2. Sampling

Sampling waters for analyses of heavy metals (cadmium and mercury) is made at the reference stations which are fixed on the lines across the major currents in the seas around Japan and on the two long meridional lines along 137°E and 155°E in the western North Pacific. A 10-liter of sea water is taken by Van Dorn water sampler and stored in a polyethylene bottle, to which 100ml of concentrated hydrochloric acid of guaranteed reagent quality is added. Analyses are made three months after the sampling.

3. Analytical method

Examining the solvent extraction methods, the present authors have found the following reagents and procedures are satisfactory.

3-1. Reagents

(1) Standard cadmium solution: Dissolve 0.1g of cadmium metal (99.9%) in a few ml of 6 N hydrochloric acid and a few drops of concentrated nitric acid, and dilute the solution to 2 liters with distilled water. This solution (50 mg/l) is diluted as required for calibration.

(2) 20% potassium sodium tartrate solution: Dissolve the recrystallized potassium sodium tartrate.

(3) 10% hydroxylamine hydrochloride solution: Prepare fresh reagent every week.

(4) Buffer solution: Prepare the ammonium buffer by mixing 2 N ammonium chloride and ammonium hydroxide in a ratio of about 1.5 to 1.0.

(5) 2 N hydrochloric acid

(6) 0.03% dithizone in carbon tetrachloride

3-2. Procedure

To 5 liters of sample water, add 50ml of potassium sodium tartrate solution and 20ml of hydroxylamine hydrochloride solution. Make the solution alkaline with ammonium hydroxide using thymol blue indicator and adjust the pH of the solution to about 10 by addition of 100ml buffer solution. The sample solution is divided into six separatory funnels of 1 liter volume. Extract the cadmium by shaking for 5 minutes using a mechanical shaker after the addition of 15ml of dithizone carbon tetrachloride solution in each funnel. Stand the mixture for about

one hour to separate the solution and the solvent. Solvents in six funnels are gathered into a separatory funnel and washed with 50ml of distilled water by shaking to remove the water soluble impurities. (Residual cadmium in the aqueous layer in six funnels is re-extracted by shaking with 15ml of carbon tetrachloride.) Then, re-extract cadmium in the whole solvent in 10ml of 2N hydrochloric acid and reject the lower solvent layer. Consequently, the cadmium concentration of the resulting solution is 500 times that of the sample water. The contents of cadmium in the concentrated solution are measured by the atomic absorption spectrophotometry.

3-3. *Apparatus and condition of measurement*

For the atomic absorption measurement the Hitachi Atomic Absorption Spectrophotometer model 303 equipped with the Hitachi Recorder model 056-1001 has been used. The operating conditions of the instrument are adjusted as follows: 228.8 nm cadmium line, 12 mA of lamp current, the flow amounts of gases 13 liter/min. of air and 3 liter/min. of acetylene.

3-4. *Sensitivity and error*

In the present method the limit of detection is as low as $0.01\mu\text{g/l}$ and fairly good recovery of added cadmium, more than 96%, is obtained. The blank of the reagents is about $0.02\mu\text{g/l}$. The experimental error is less than 10% at the content level of $0.5\mu\text{g/l}$.

4. Results and Discussion

The contents of cadmium in sea water in the adjacent seas of Japan and in the western North Pacific are shown in Fig. 1-4. The highest value, $1.61\mu\text{g/l}$, is found in surface water off the Shiryazaki. Cadmium contents in surface waters fluctuate with location, ranging from 0.00 to $0.65\mu\text{g/l}$. Sometimes relatively higher values are found in the adjacent regions of Japan, while the lower values, less than $0.1\mu\text{g/l}$, are found in the offshore region. The average content of cadmium in surface waters is $0.07\mu\text{g/l}$ in the adjacent regions of Japan and $0.05\mu\text{g/l}$ in the western North Pacific. Cadmium contents in deep waters do not fluctuate so much with location and are significantly higher than those in surface waters. The average in deep waters is $0.11\mu\text{g/l}$.

From the obtained distribution of cadmium in sea water it appears that the

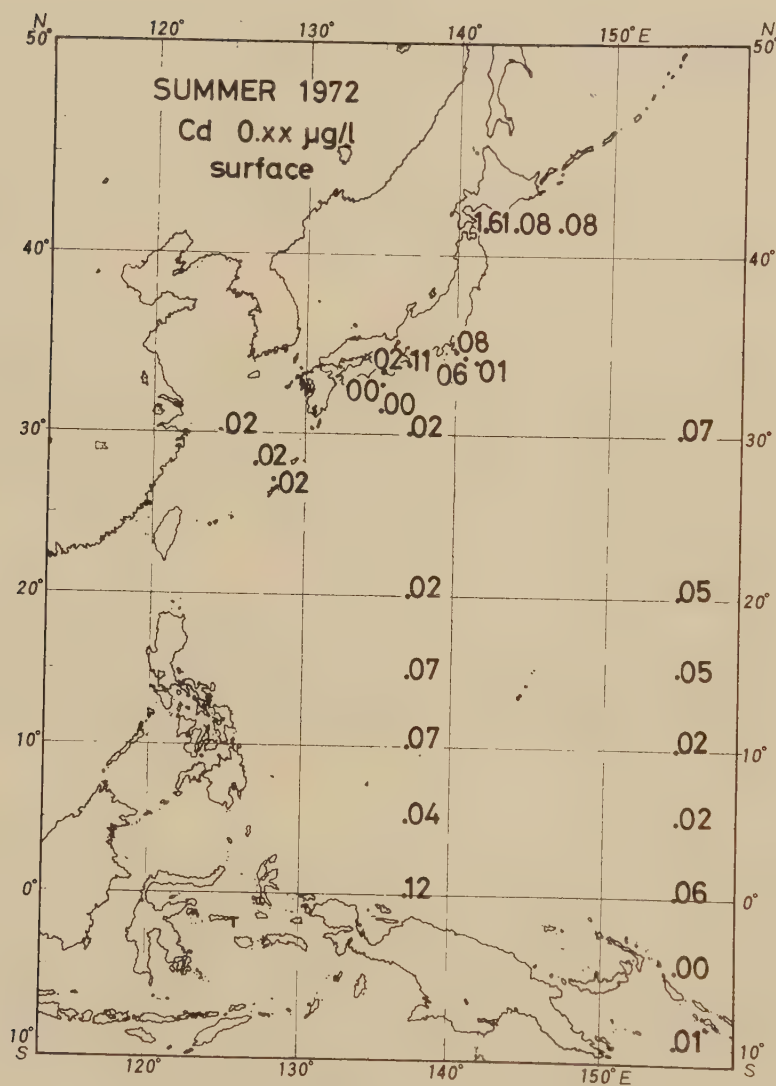


Fig. 1. Cadmium contents in surface waters in summer 1972 ($\mu\text{g/l}$).

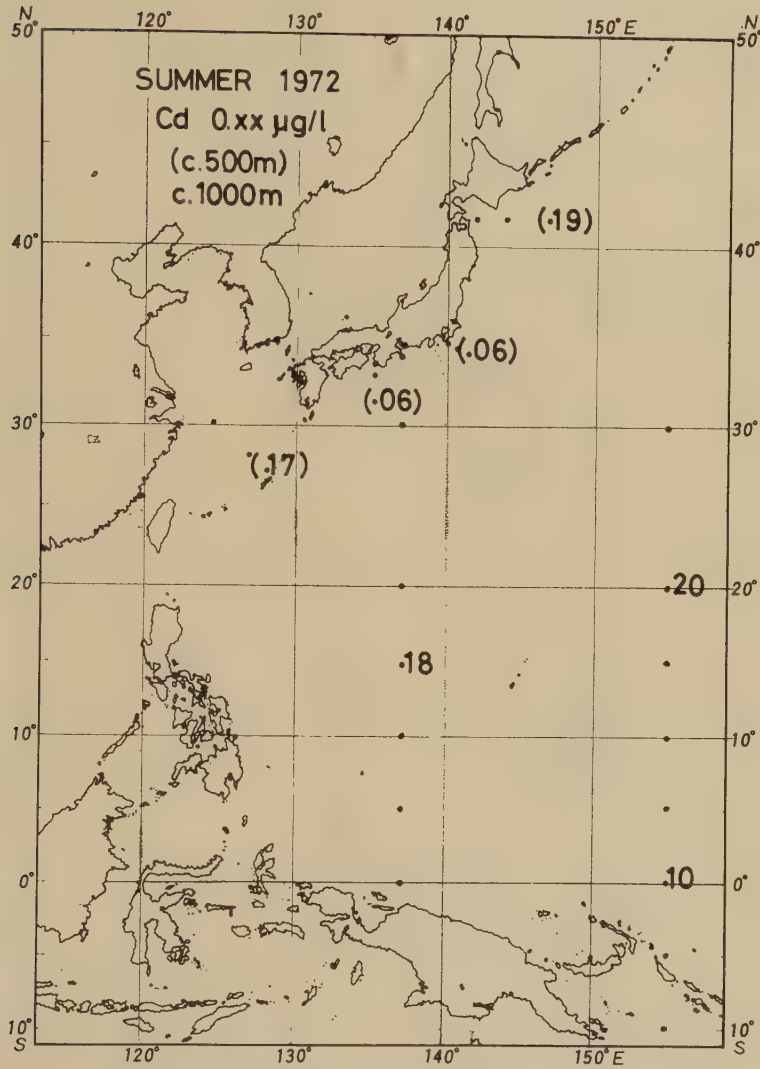


Fig. 2. Cadmium contents in deep waters in summer 1972 ($\mu\text{g/l}$).

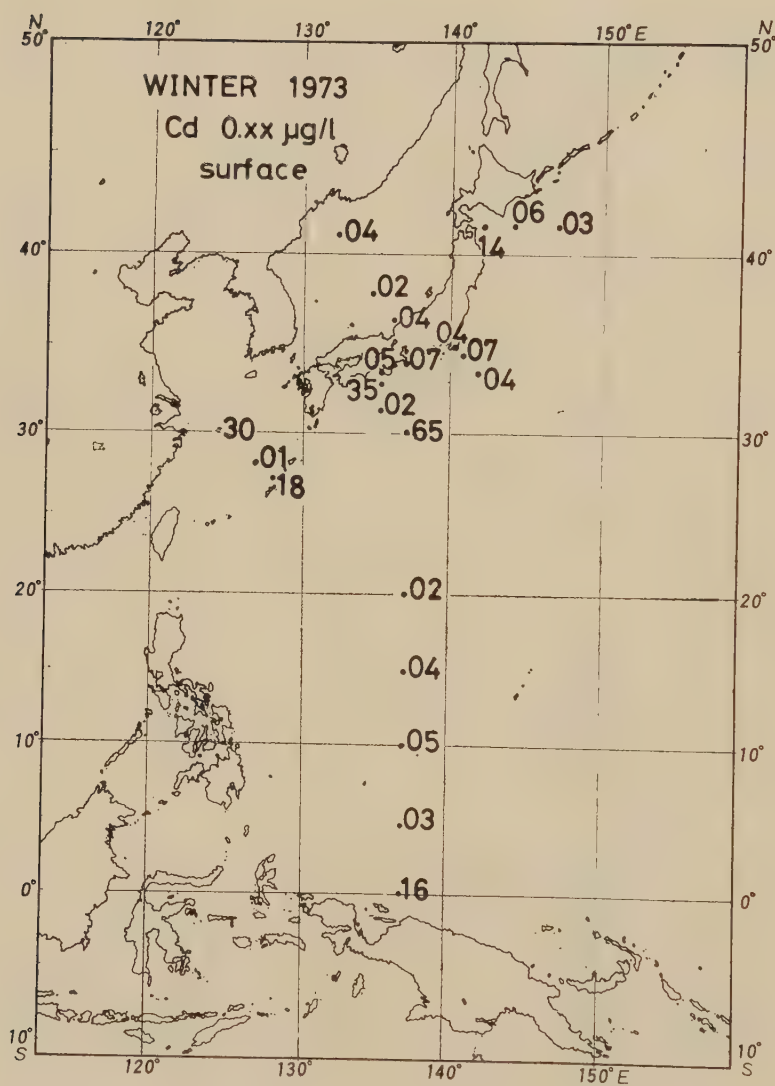


Fig. 3. Cadmium contents in surface waters in winter 1973 ($\mu\text{g/l}$).

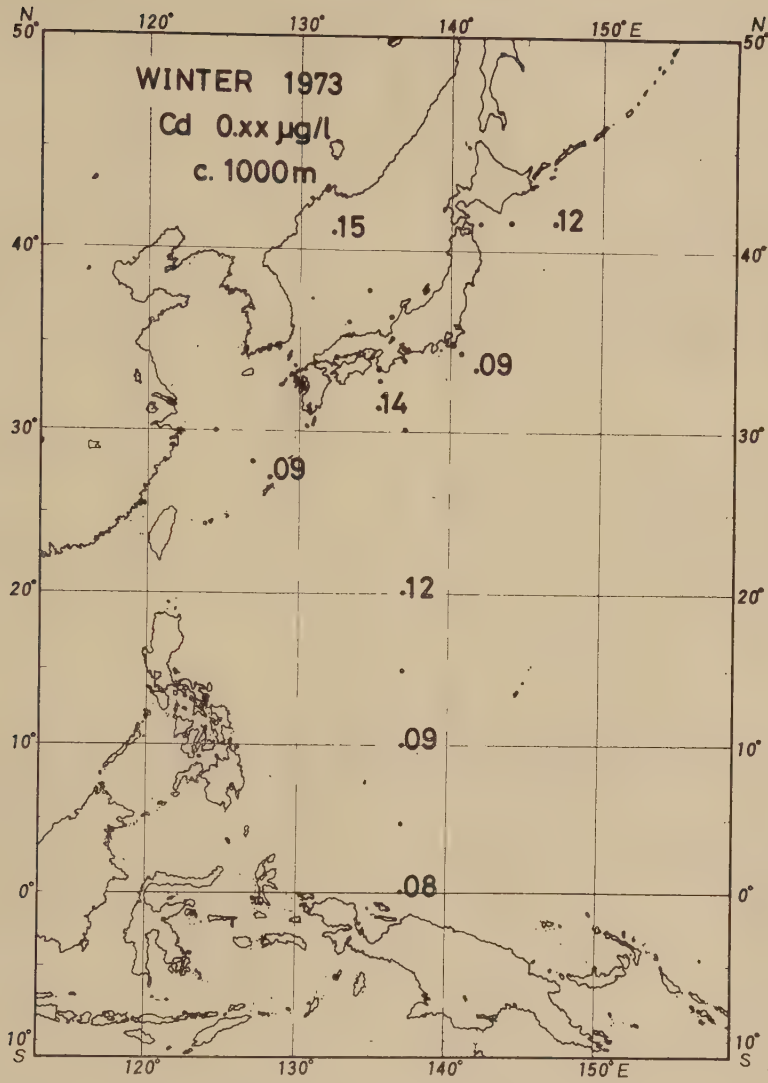


Fig. 4. Cadmium contents in deep waters in winter 1973 ($\mu\text{g/l}$).

Table 1. Cadmium contents in sea water in the adjacent seas of Japan ($\mu\text{g/l}$)

Location	1972		1973	
	summer	autumn	winter	spring
41°30' N, 142°00' E	1.61	0.05	0.14	0.08
41°30' N, 144°00' E	0.08	0.07	0.06	
41°30' N, 147°00' E	0.08	0.15	0.03	0.07
"	0.19*	0.15*	0.12*	0.14*
35°00' N, 140°10' E	0.08		0.04	0.06
34°31' N, 140°35' E	0.06		0.07	
33°30' N, 141°30' E	0.01	0.02	0.04	0.07
"	0.06*	0.06***		0.09**
33°30' N, 135°15' E	0.02	0.02	0.05	0.03
32°40' N, 135°15' E	0.00	0.05	0.34	
31°20' N, 135°15' E	0.00	0.00	0.02	0.38
"	0.06*	0.00*	0.05*	0.14**
27°30' N, 128°08' E	0.02	0.04	0.18	0.07
"		0.17*	0.09*	0.01*
28°24' N, 126°54' E	0.02	0.04	0.01	
30°00' N, 132°17' E	0.02	0.05	0.03	0.00
36°08' N, 135°51' E			0.04	0.03
37°43' N, 134°43' E			0.02	
41°00' N, 132°17' E			0.04	0.02
"				0.15**

*: 500m, **: 1,000m, ***: 100m

Table 2. Cadmium contents in sea water in the western North Pacific along the meridian of 137°E and 155°E ($\mu\text{g/l}$).

Latitude	summer 1972		winter 1973
	137°00' E	155°00' E	137°00' E
34°00' N	0.11		0.07
30°00' N	0.02	0.07	0.65
20°00' N	0.02	0.05	0.02
"		0.20*	0.12*
15°00' N	0.07	0.05	0.04
"	0.18*		
10°00' N	0.07	0.02	0.05
"			0.09*
5°00' N	0.04	0.02	0.03
0°00'	0.12	0.06	0.16
"			0.08*
5°00' S		0.00	
10°00' S		0.01	
"		0.10*	

*: 1,000m

artificial addition of cadmium from land area into the sea is clearly occurring. For the higher contents of cadmium in deep water, the biological transport is supposed to be effective: cadmium supplied at the sea surface is taken up by marine organisms and resolves out into the sea from the dead organisms as they are sinking. Higher concentrations in marine organisms than in surrounding sea water reported by the previous workers (Mullin & Riley, 1956) may substantiate this mechanism.

Mullin and Riley (1956) reported the contents of cadmium in sea water in the Irish Sea and of the English Channel was $0.11\mu\text{g/l}$ on the average, ranging from 0.024 to $0.25\mu\text{g/l}$. Sugawara et al (1973) obtained the average value of $0.064\mu\text{g/l}$, ranging from 0.01 to $0.37\mu\text{g/l}$ in the western North Pacific. Contents of cadmium in sea water reported in the present paper seems to be in good agreement with those reported by previous investigators.

Acknowledgements

The authors wish to express their best thanks to Prof. Y. MIYAKE and Dr. Y. SUGIURA for their valuable advice. They are indebted much to Dr. O. ASAOKA and Mr. K. KIMURA for their cooperation in this work.

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日本近海・北西太平洋海域海水中的カドミウム含量

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海水中のカドミウム含量を原子吸光分析法で測定した。測定前にジチゾン・四塩化炭素による抽出と塩酸による逆抽出法により、試海水のカドミウム濃度を 500 倍濃縮した。

日本近海を含む北西太平洋海域表面海水中的カドミウム含量は、 $0.00\sim 0.65\mu\text{g/l}$ の範囲にあり、平均値は $0.06\mu\text{g/l}$ である。また 1,000m 深海水中的カドミウム含量は平均値で $0.11\mu\text{g/l}$ であり、表面海水よりもやや高い値を示す。

気象庁
欧 文 海 洋 報 告
第 25 卷

THE
OCEANOGRAPHICAL MAGAZINE

Vol. 25



Published by the Japan Meteorological Agency

1 9 7 4

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昭和49年3月30日 発行

編集兼
発行者

気 象 庁

東京都千代田区大手町1の3の4

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昌美印刷株式会社

東京都千代田区神田錦町3の16

